CHAPTER 5 -- PROPOSED MINIMUM FLOW CRITERIA (RESULTS)

INTRODUCTION

The following chapter describes the basis for establishing the MFL criteria as required in Chapter 373, Florida Statutes for the Loxahatchee River and Estuary. This chapter provides a summary of the scientific approach and technical relationships that were evaluated in defining significant harm for the water body and a detailed presentation of the proposed MFL criteria with supporting documentation.

Once the water resource functions of the river and estuary that need to be protected by the establishment of the MFL were identified (**Chapter 2**) and specific technical relationships were developed and evaluated to define significant harm for the water body. The following sources of information were reviewed and considered in the development of these criteria:

1. **Literature Review**: Results of a literature search produced a bibliography containing nearly 100 citations (**Appendix A)** concerning technical relationships among flow, salinity, hydrodynamics and key biological indicator communities and species for the Northwest Fork, the downstream estuary and similar systems. This review involved (a) review of previous studies that identified relationships among river flow, salinity and resource protection; (b) identification of species or biological communities that could potentially be used as indicators, targets, or criteria for determining a minimum flow for the river and the estuary; and (c) determination of how these indicator species or indicator communities have been impacted by historic hydrologic alterations within the watershed.

2. **VEC Approach:** A “Valued Ecosystem Component” (VEC) approach similar to that developed by the EPA (1987) was developed to establish a minimum flow regime that will protect important components of the river ecosystem from significant harm.

3. **Historical Flow and Salinity Data**: Review of available USGS and SFWMD flow data and stage records was conducted using the DBHydro database for the Lainhart Dam, Cypress Creek, Hobe Grove Ditch, and Kitching Creek. These data were analyzed in terms of descriptive statistics, and reviewed for trends (**Appendix D**). Historical salinity data provided by the Loxahatchee Environmental Control District for four sites along the river were also reviewed. The long-term flow records and collected salinity database were used as input to a hydrodynamic salinity model developed for the river and estuary (**Appendix E**).

4. **Aerial Photography/GIS studies**: Review and interpretation of historical black and white aerial photographs from 1940, 1953, 1964 and color infrared photos from 1979, 1985 and 1995 were used to quantify and document changes over time in the distribution

of the dominant plant communities that comprised the floodplain swamp, wetlands and uplands located along the river corridor**.**

5. **River Vegetation Survey**: Two vegetation surveys were conducted along the NW Fork of the river to characterize the species and community changes that occur along the salinity gradient upstream from the Jupiter Inlet. These surveys provided both community-based (i.e., canopy structure analysis, total number of observed species, community composition) and species-based (i.e., abundance, number of individuals, height, trunk diameter, age class) information which was used to examine relationships between salinity conditions and vegetation, as well as to construct a model that relates long-term salinity conditions with current vegetation community parameters.

6. **Soil Salinity Samples.** District staff collected soil samples along the Northwest Fork in January 2002 to investigate soil salinity concentrations and provide a basis future sampling projects. Four transects were established across the river floodplain, at sites representing different degrees of salinity exposure from tidal flux, and extended from the riverbank to the edge of the upland-floodplain ecotone.

7. **Hydrodynamic/salinity Model**: A two-dimensional depth-averaged finite element hydrodynamic/salinity model (RMA-2 and RMA-4 codes) was used to generate a long-term simulated mean daily salinity times series for each river vegetation sampling site. Descriptive statistics (mean, standard deviation, median, mode, maximum) were calculated to describe the salinity regime for each site and analyzed in terms relevant to the river's vegetation community (i.e., calculation of salinity magnitude, duration of each event, and the period of time between events). A database was developed for each of the seven sites relating measured vegetation community parameters with data derived from the simulated 30-year salinity record.

8. **Vegetation/Salinity Model:** Where highly correlated relationships were found between measured vegetation parameters and modeled long-term salinity conditions, formulas were developed to describe these relationships and a deterministic regression model was constructed to predict (extrapolate) long-term vegetation community response to salinity. A vegetation/salinity model was developed and used to determine salinity conditions and flows associated with plant community parameters.

9. **Consumptive Use Permit Analyses:** The overall effect of consumptive uses (public water supply, agriculture, and self-supplied residential wells) on providing flows to the Northwest Fork of the Loxahatchee River was also investigated. SFWMD staff reviewed and analyzed data from permit applications and conducted groundwater model simulations to estimate the relative effect of consumptive uses on water levels in the Loxahatchee Slough and deliveries to the Northwest Fork of the Loxahatchee River during wet, normal and dry periods.

RESULTS OF LITERATURE REVIEW

One requirement for developing minimum flow and level criteria is to use "best available information". The Loxahatchee River has been the focus of numerous studies over the past three decades. A literature review was conducted to review the results of these studies as they may relate to defining a flow/salinity relationship or recommended minimum flow for the Loxahatchee River. Results of the literature review as well as an accompanying bibliography of these studies are provided in **Appendix A** of this report**.** The literature review is organized chronologically beginning in the early 1970s when the problem of saltwater intrusion in the Northwest Fork was first identified in the scientific literature as a major public concern. Major findings derived from this review are summarized below.

1. The Loxahatchee River and estuary is a small (544 km^2) shallow-water body in southeastern Florida that empties into the Atlantic ocean at the Jupiter Inlet. Historical evidence indicates that the inlet periodically opened and closed to the sea as a result of natural events. Originally, freshwater and tidal flows kept the inlet open for some of the time. Near the turn of the century, some flow was diverted by construction of the Intracoastal Waterway and the Lake Worth Inlet and by modification of the St. Lucie Inlet. Subsequently the Jupiter Inlet remained closed for much of the time until 1947. Since 1947, the inlet has been permanently open (Wanless et al. 1984).

2. Fresh water enters the NW Fork of the Loxahatchee River primarily through four major tributaries. Flows received from the Loxahatchee Slough and G-92, on average, represent approximately 57% of the total flow (as measured at SR 706) delivered to the NW Fork, while Cypress Creek contributes another 32%, Hobe Grove Ditch 7% and Kitching Creek, 4% (Russell and McPherson, 1984). See also **Table 22** of this Report.

3. In the early 1970's it was recognized that hydrologic alterations of the watershed have reduced freshwater flow delivered to the river causing the upstream movement of saltwater during dry periods as well as saltwater intrusion of the local ground water aquifer (Land et al. 1972, Rodis 1973, Birnhak 1974). The primary cause of observed changes in flora and fauna along the NW Fork of the River was identified as the upstream movement of saltwater during drought periods (Rodis 1973, Birnhak 1974, Alexander and Crook 1975, FDNR 1985, Duever and McCollum, 1982). These studies recommended that to maintain and protect the natural communities of the Northwest Fork, sufficient freshwater should be redirected from inland canals and water storage areas to the Loxahatchee River.

4. Rodis (1973) recommended that a constant freshwater flow of 50 cfs delivered over the Lainhart Dam would be required to restrict the upstream movement of saltwater and preserve remaining natural communities in the middle and upper reaches of the NW Fork. This recommendation included an assumption that other contributing tributaries (Cypress Creek, Hobe Grove Ditch and Kitching Creek) would provide an additional 80 cfs.

5. Birnhak (1974) suggested that flows of about 60 cfs from Lainhart Dam to the Northwest Fork would keep saltwater intrusion below Station 5 near Kitching Creek (river mile 8).

6. Alexander and Crook (1975) produced a comprehensive study of the major changes in vegetation that have occurred in South Florida over the last 30 or more years. One of their study plots included an area of the Northwest Fork near the mouth of Kitching Creek. Based on photo-interpretation of aerial black and white photos taken from 1940 and 1970 they concluded that since 1940, wet prairie and cypress swamp hardwoods had lost ground to pineland and mangrove communities due to a lowering of the groundwater table and invasion of saltwater between river miles 6 and 8.

7. Each of these studies identified the presence of a freshwater layer of water overlying denser seawater within the estuary and portions of the Northwest Fork. This vertical stratification of the water column, or saltwater wedge, is a common feature of estuaries. The upstream tip of the saltwater wedge is characterized as a bottom salinity that exceeds 2 parts per thousand (Russell and McPherson 1984, Mote Marine Lab, 1990b) as shown in the conceptual diagram below (**Figure 18**). Salinity studies conducted within the river (Russell and McPherson, 1984) indicate the average distance of the salinity wedge between top and bottom is approximately 0.5 miles (**Figure 18**). During periods of reduced freshwater input, the saltwater wedge may extend as far as 5 to 10 miles upstream of the Northwest Fork. The saltwater wedge was reported to move daily from 0.5 to 1.5 miles up and down the river in response to freshwater inflow and daily tidal fluctuations (Russell and McPherson, 1984).

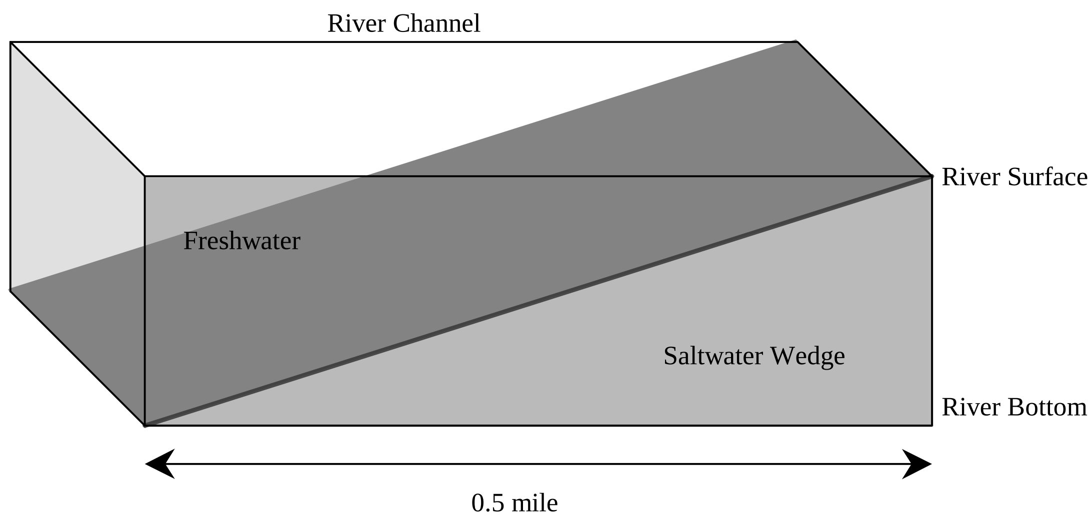


Figure 18. Conceptual diagram of the saltwater wedge

8. Russell and McPherson (1984) conducted an intensive study of the relationship of salinity distribution and freshwater inflow in the Loxahatchee River estuary from 1980-1982. Freshwater inflows to the major tributaries were measured at six continuous gauging stations including the Northwest Fork, Cypress Creek, Hobe Grove Ditch, and Kitching Creek. Key results of this study showed that the total amount of freshwater [from all sources] needed to restrict brackish water (>2 ppt) from the upstream reaches of the Northwest Fork at mean high tide were estimated to be as shown in **Table 22.**

Table 22. Total mean daily discharges to the Northwest Fork and corresponding upstream extent of the saltwater wedge in river miles (from: Russell and McPherson 1984)

Total* Mean Daily Freshwater Discharge (cfs)	Upstream extent of saltwater wedge in river miles
220	7.0
130	8.0
120	8.2
75	9.0
43	10.0
26	11.0

* Includes NW Fork + all upstream tributaries

Figure F-4, Appendix F provides a summary of salinity profiles (at high tide) developed by Russell and McPherson (1984) for the Northwest Fork under various flow discharge rates. Russell and McPherson (1984) also noted that maintaining the above flow regime would not protect the river under all conditions. During extreme high tides and storm events, saltwater could still move upstream for brief periods. Based on the flow/salinity relationships provided above, the total amount of freshwater (from all sources) needed to restrict the saltwater wedge from the upstream reaches of the river was determined to be 120 cfs at river mile 8.2, for example, which islocated upstream of the confluence of Kitching Creek and the Northwest. Of this total flow, 57% (or about 68 cfs) is derived from the Northwest Fork, 32% (38 cfs) from Cypress Creek, 7% (8 cfs) from Hobe Grove Ditch, and 4% (5 cfs) from Kitching Creek.

9. Law Environmental (1991a) summarized unpublished SFWMD flow, salinity and rainfall data collected from 18 sites within the Northwest Fork and downstream estuary from 1985-1988. Average and median flows discharged to the Northwest Fork of the river through G-92 were recorded as 50 and 56 cfs, respectively over the 3-year study. Average bottom salinity recorded at river miles 9.2, 8.0, 6.9, and 5.7 were 0.4, 2, 8, and 17 ppt, respectively. Vertical stratification of the water column was most prominent at river miles 2.6 and 8.0. Under extreme low flow conditions the salinity wedge was transported upstream by slightly more than one river mile. Under these low flow conditions, average bottom salinity recorded at river miles 9.2, 8.0, 6.9, and 5.7 were 3, 13, 17, and 25 ppt. Surface and bottom salinity at river mile 8, located within the area of cypress die-off, was less than 0.2 ppt and 0.4 ppt for 50% of the 1985-1988 data set. Discharges from S-46 were reported to have substantial effects upon salinity regimes many miles upstream of the Northwest Fork. The report concluded that salinity control by a regulated freshwater discharge at average flow conditions of 40 to 50 cfs could benefit the ecosystem by establishing a stable salinity wedge location for the estuary system.

10. McPherson and Halley (1996) in their publication, *The South Florida Environment: A Region Under Stress,* documented the encroachment of mangroves, along with the overall reductions in freshwater flows, maintenance of lower groundwater levels, short duration high volume freshwater flows for flood protection, and changes in the quality of runoff.

11. More recent studies conducted by Dent and Ridler (1997) indicate that flows delivered to the Northwest Fork (as measured at SR 706) that are equal or below 50 cfs, may not be sufficient to maintain freshwater conditions (less than 2 ppt) as far downstream as river mile 8. Their data indicated that over a one-year monitoring period, the 50 cfs target was met only 33% of

the time. When flow was equal to or less than 50 cfs, bottom salinity exceeded 2 ppt upstream of water quality monitoring station 65 (river mile 8.6) 95% of the time while station 64 (river mile 7.7) exceeded 2 ppt 100% of the time. This report proposed a minimum flow rate of 75 cfs (as measured at SR 706 bridge) for the end of the dry season (May) and 130 cfs for the wet season (July-November). They also recommended a maximum flow range, i.e., discharges should not exceed 150 cfs during the months of February-May, and no greater than 300 cfs during the wet season (June-November).

12. Dent and Ridler (1997) also provide information as to the sensitivity in which salinity concentrations within the river react to changes in flow. For example at water quality station 65 (river mile 8.6), a drop in the upstream flow rate from 150 cfs to below 60 cfs over a five day period resulted in the almost immediate movement of salt water into the area.
13. Salinity studies were also conducted by the Loxahatchee River Environmental Control District to determine the effects that physical modifications to the river and estuary, such as filling man-made gaps between the winding oxbows in the Northwest Fork had on salinity conditions in the river. Analyses of salinity data collected before and after the barriers were installed indicate that by redirecting the flow of the river through the original meandering oxbows of the river, approximately 0.7 river mile were restored to the distance needed for saline tidal waters to move upstream. These modifications resulted in a decline in salinity levels upstream of the gaps (Dent 1997).
14. As late as 1998, the original USGS flow target of 50 cfs established by Rodis (1973) was still identified as the recommended minimum flow target for the Northwest Fork. The origin of this target was based on water flowing over the Lainhart dam; a broad crested weir located 0.1 mile north of SR 706. Previous flow rating curves developed for the dam in 1984 tended to under estimate flow over the dam. The dam was reconstructed in 1998 and flow-rating curves developed for the dam tended to significantly over estimate discharge. For this reason District staff conducted a re-calibration of the rating curve for the Lainhart dam in 1998. Re-calibration of the dam and subsequent statistical review of this new flow/salinity information resulted in the recommendation that a minimum flow target of 64 cfs was needed to maintain the saltwater wedge (as 2 ppt bottom salinity) just downstream of the confluence of Kitching Creek and the Northwest Fork of the river (SFWMD 1999). Details of the re-calibration procedure and a summary of the statistical results are provided in **Appendix D** of this report.
15. Several studies also recommended consideration of the construction of a saltwater barrier to reduce the upstream movement of saltwater during dry periods.

Based on results of the literature review, a number of flow levels have been proposed for the Northwest Fork of the Loxahatchee River during the past 30 years, ranging from a constant flow of 50 cfs to recommended dry and wet season flows of 75-130 cfs. Although these studies have produced valuable information concerning river flow and salinity relationships, none were developed based on the specific statutory minimum flows and levels requirements of Chapter 373.042(1) F.S. that addresses the concept of significant harm, i.e. flow conditions that would need to be maintained during infrequent low flow conditions associated with a regional drought.

HYDROLOGIC AND SALINITY CONDITIONS

Sources of Freshwater Inflow

Northwest Fork

Table 23 provides a summary of average freshwater flows delivered to the three forks of the Loxahatchee estuary during the wet and dry season as well as during selected drought events. Four major sources of water (G-92 and the Lainhart Dam, Cypress Creek, Hobe Grove Ditch and Kitching Creek) provide the majority of freshwater flow to the Northwest Fork of the Loxahatchee River. Other historical inputs such as Moonshine Creek and Wilson Creek have been highly altered by drainage and development and today provide only a very small portion of flow to the Northwest Fork and are not included in **Table 23.** Of these four sources, the Lainhart Dam (the main stem of the river) is the largest contributor, providing between 51 and 56 percent of the flow to the Northwest Fork during the wet and dry seasons.

Table 23. Summary of Average Wet and Dry Season Flows to the Loxahatchee Estuary.

Tributary	Average Daily Flow (cfs)		1980-81 drought Avg. flow (cfs)		1989-90 drought Avg. Flow (cfs)		Period of Record
	Wet Season	Dry Season[1]	Wet Season	Dry Season	Wet Season	Dry Season	
Northwest Fork							
Lainhart Dam	95	70	65	35	68	26	1971-2001
Cypress Creek	60	32	57	30	41	30	1980-1991
Hobe Grove Ditch	9	7	11	7	9	7	1979-1991
Kitching Creek	21	16	8	5	3	1	1979-2001
Subtotal	*185*	*125*	*141*	*77*	*121*	*64*	
North Fork[2]							
USGS sites 28B & 28c	4	1	4	1	ND	ND	1980-1982
Southwest Fork							
C-18 Canal@S-46	94	61	61	20	8	8	1961-2001
Total	283	187	206	98	129	72	

[1] Wet season defined as May 15- Oct. 15; Dry season = Oct. 16- May 14
[2] From Russell and McPherson 1984 (POR 1980-1982)

The second largest contributor is Cypress Creek representing 26 – 32 percent of the total flow delivered to the Northwest Fork, followed by Kitching Creek (11-13%) and Hobe Grove Ditch (5%). In terms of average dry season flows, the Lainhart Dam provides about 70 cfs, Cypress Creek, 32 cfs; Kitching Creek, 16 cfs; and Hobe Grove Ditch, 7 cfs for an average total of 125 cfs of freshwater delivered from the Northwest Fork to the Loxahatchee estuary (**Table 23**). These dry season flows were reduced by more than one-half during 1980-1981 and 1989-90 drought periods with average values ranging between 26-35 cfs for the Lainhart Dam, Cypress Creek (30 cfs), Hobe Grove Ditch (7 cfs) and Kitching Creek (1- 5 cfs) for an average total of only 64 -77 cfs of flow discharged to the estuary during low rainfall periods (**Table 23**).

Review of historical flow data from over the past 30 years shows that flows delivered to the Northwest Fork have significantly increased since 1990 **(Figure 19**), due in part to (a) operational improvements (enlarged culverts and an automated gate) made to the G-92 structure shortly after the river was designated as Florida's first Wild and Scenic River, and (b) increased rainfall experienced during the 1990's. Average rainfall from 1971 to 1989 was 59 inches per year, whereas average rainfall from 1990-2000 was 70 inches per year (**Figure 4, Chapter 2**). In comparison to the 1970's and 1980's, surface water flows delivered to the river via G-92 during the 1990's increased by about 34 cfs on average (**Figure 19**). **Table 24** indicates how the distribution of flows changed at different flow rate thresholds. In general the percentages of time that flows to the river were less than 65, 50, 35 and 25 cfs have decreased. Over the past decade, the 65-cfs flow target for the Lainhart Dam, as proposed in the northern Palm Beach County Comprehensive Water Management Plan, is met about 57% of the time. Even though a number of hydrological improvements have been made within the basin over the last decade, there are still periods of time when the river receives very little flow. The occurrence of flow rates less than 10 cfs increased slightly from 6% to 7% during the last 12 years (**Table 24**).

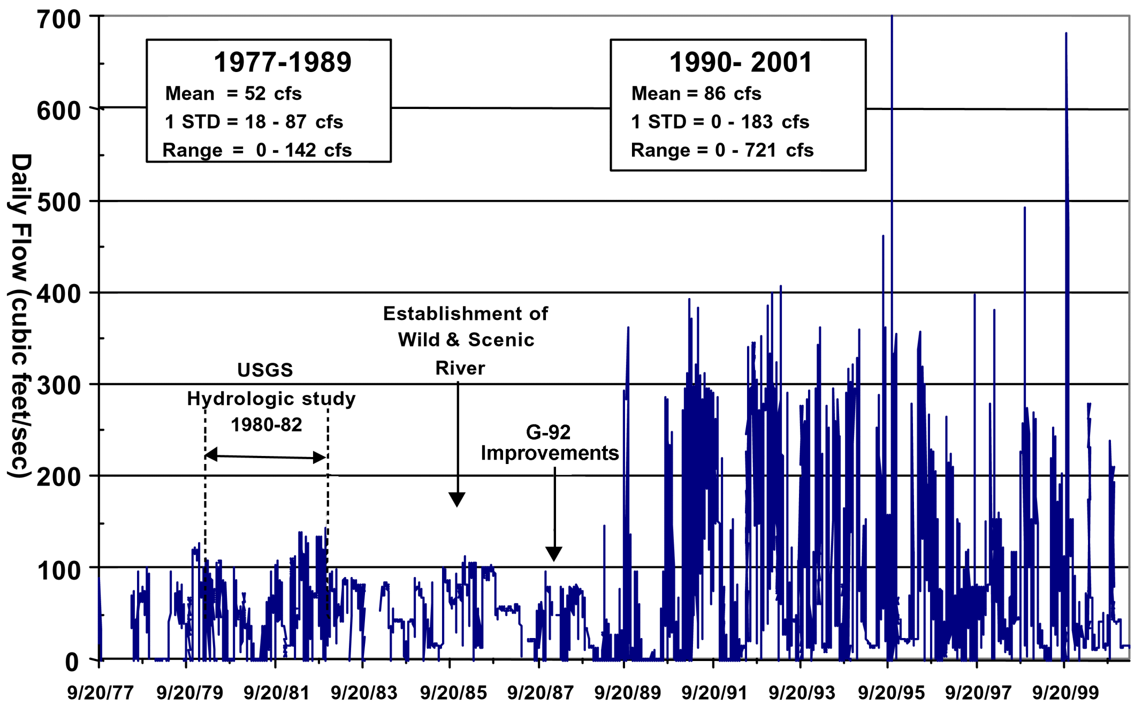


Figure 19. G-92 Historical Flows Delivered to the Northwest Fork.

Table 24. Comparison of historical and more current flow conditions at the Lainhart Dam (Northwest Fork of the Loxahatchee River) based on USGS data from 1971 to 2000.

Flow Rate	Historical (1971-1989)*				Current (1990-2001)**			
	% of time below desired flow rate	No. of Events	Avg. Duration (days)	Return Frequency (months)	% of time below desired flow rate	No. of Events	Avg. Duration (days)	Return Frequency (months)
65 cfs	58 %	124	32	1.8 months	43 %	107	16	1.3 months
50 cfs	47 %	113	29	2 months	36 %	101	15	1.4 months
35 cfs	34 %	94	24	2.4 months	25 %	73	15	2 months
20 cfs	16 %	59	19	3. 8 months	15 %	35	18	4 months
10 cfs	6 %	26	16	8.6 months	7 %	16	19	8.8 months

* =18.75 year period of record, ** =11.8 year period of record

Presently, G-92 is the only structure that can be controlled by the District through remote telemetry to release water from the Loxahatchee Slough and C-18 canal to the Northwest Fork. The other three tributaries do not have controllable structures. For the most part, flows from these structures are primarily rain-driven. Surface water flows from G-92 combine with surface water runoff from the Jupiter Farms area and SIRWCD C-14 canal to convey water to the Lainhart Dam, the primary source of freshwater for the Northwest Fork. A time series of historical flow data (1971-2001) for the Lainhart Dam is provided in **Appendix H**. These data are summarized in the following flow duration curve presented in **Figure 20.** The median (50th percentile) flow value for the Lainhart Dam is 60 cfs, while the 90th, 75th, 25th and 10th percentiles are 14, 29, 105 and 173 cfs, respectively.

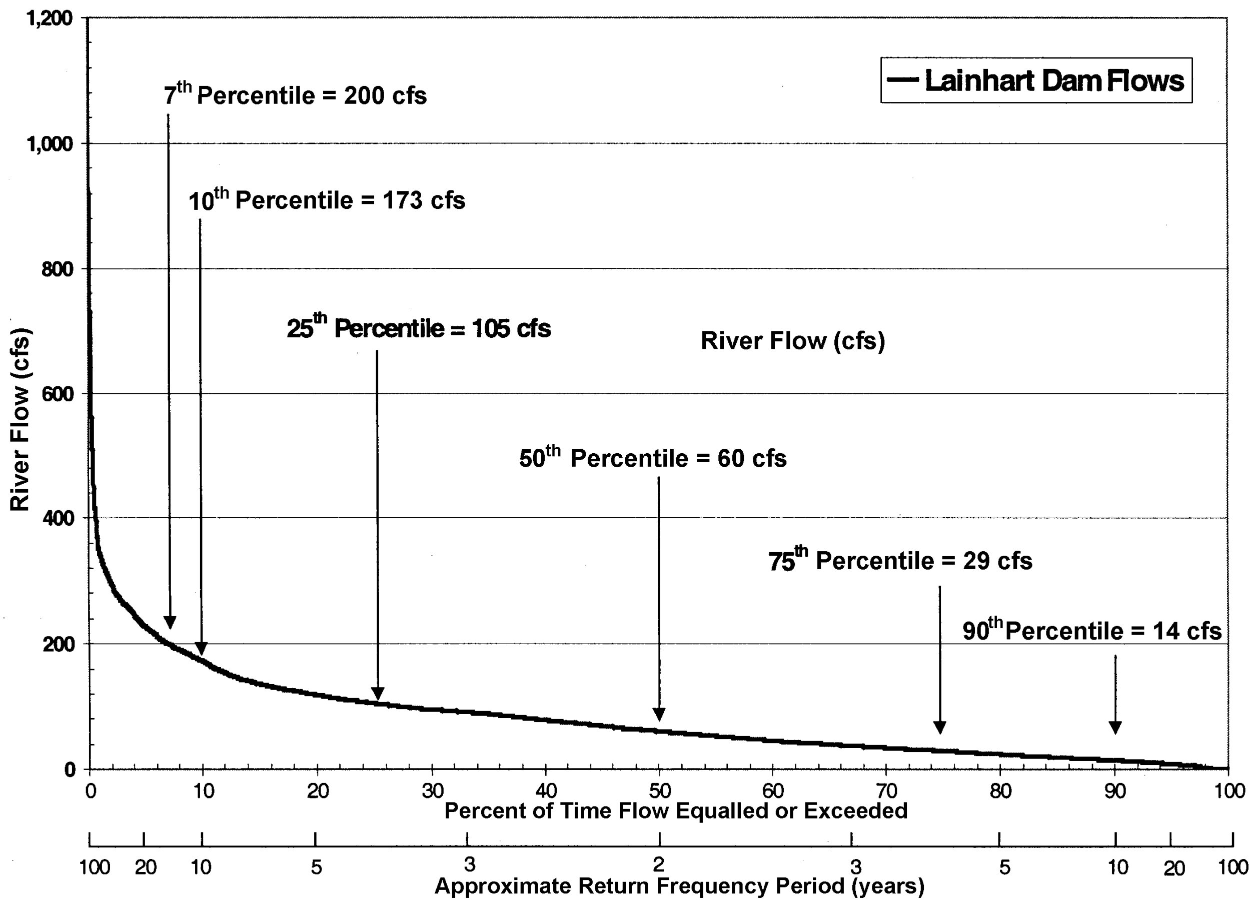


Figure 20. Flow Duration Curve for Lainhart Dam (1971-2001)

Under these low flow conditions (<10 cfs) saltwater has been recorded to extend upstream as far as Trapper Nelson's (river mile 10.7) with river bottom salinity values ranging up to 7 ppt (Russell and McPherson 1984). Low flow events such as these also restrict recreational use of the wild and scenic portion of river by canoers and kayakers and may potentially stress or temporally eliminate remaining species of freshwater fish or aquatic invertebrates downstream of Trapper Nelson's.

North Fork

The North Fork is a shallow tributary that currently receives only a small percentage of the total freshwater flow to the estuary (Russell and McPherson 1984; Sonntag and McPherson 1984). Brackish conditions extend approximately 5.0 miles up this branch from the mouth of the inlet (McPherson and Sabanskas 1980). The North Fork of the estuary has an average depth of 3.4 feet, maximum depth of 6.6 feet, average width of about 0.15 miles and covers a total area of about 200 acres. Freshwater flow to the North Fork is uncontrolled. A study by Russell and McPherson (1984) indicated that freshwater flow from the North Fork represented only about 2% of total freshwater flow to the estuary. Much of the upper end of the watershed of the river lies within Jonathan Dickinson State Park. The shoreline along the lower estuary is surrounded by residential development and mostly bulkheaded. The sediments generally consist of fine sand and mud. Some areas have deep pockets of soft mud that has a high content of organic material. Water quality is often poor due to high levels of turbidity and color that limit light penetration, low levels of dissolved oxygen and occasional high concentrations of fecal coliform bacteria (Dent et al. 1998). Due to the low input of fresh water, bottom salinities in the lower section of the North Fork are usually above 25 ppt, while salinities further upriver average about 14 ppt.

Southwest Fork

Under normal operating conditions discharges are made to the Southwest Fork of the estuary through the S-46 structure when stages in the C-18 canal exceed 15.0 ft. NGVD. However during a major storm event these gates are operated manually to quickly lower water levels in the canal for flood control and can maintain a headwater between 13 and 14 ft. NGVD for a short period of time. As a result, flows delivered from S-46 to the estuary are highly variable in response to upstream water management (**Figure 21**). Review of flow data collected from S-46 for the period of record 1990-2000 shows that although average flows delivered to the estuary ranged between 61 and 94 cfs for the wet and dry seasons (**Table 23**) the median value was zero. No discharges were made to estuary for 67% of the time over the period of record. In contrast, during 1995 and 1999 were there were periods when mean daily flows exceeded 2,500 cfs in response to major storm events experienced within the watershed (**Figure 21).** Events such as these are thought to have a major impact on the both water quality and the salinity in estuary.

Salinity Conditions within the Northwest Fork

Historical Data

The following information was summarized from water quality monitoring studies conducted by the Loxahatchee River Environmental Control District (Dent 2002, personal communication). The database includes information periodically collected from 1970 up to 2001. For the following analysis, water quality monitoring sites area were grouped into segments defining different salinity zones, or habitats, found within the estuary and River. These include the marine and coastal zone, estuary, wild & scenic segment, and freshwater tributaries. Measured salinity data for these river segments are presented in **Table 25.**

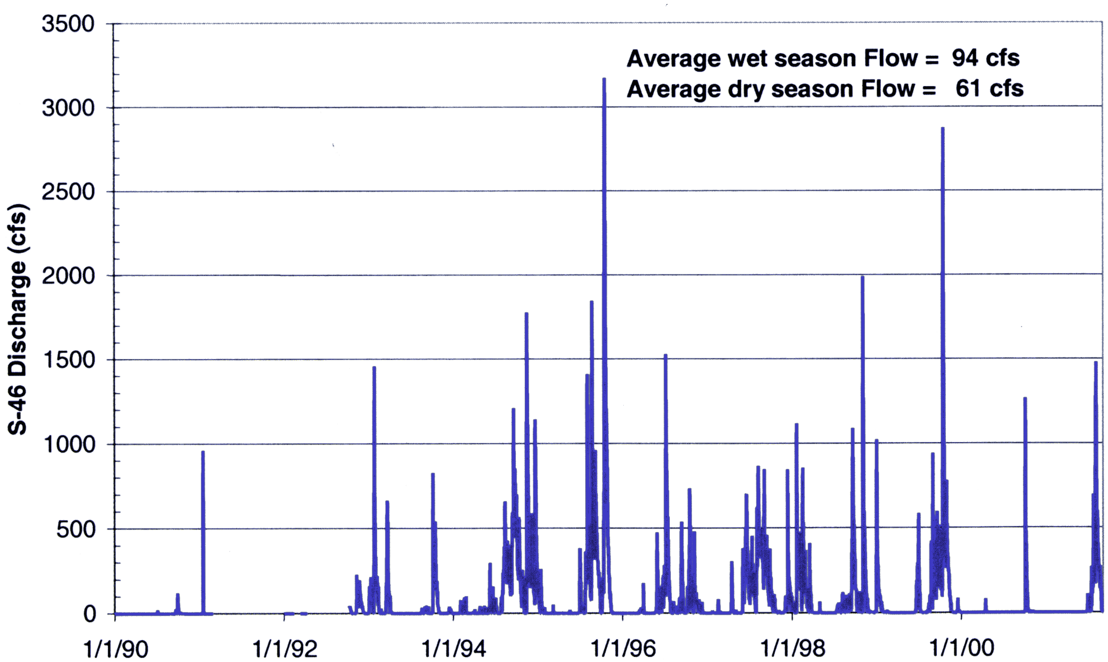


Figure 21. Water Management Releases from the C-18 canal via S-46 (1990-2001)

Table 25. Measured salinity from the NW Fork of the Loxahatchee River.*

River Segment	Period	Comments	Mean Salinity (ppt)
Marine/Coastal	1970-1981	12-year period	27.7
	1982-1993	12-year period	29.0
	1994-1997	Above-average rainfall years	30.7
	1998-2001	Drought years	30.6
Estuarine	1970-1981	12-year period	22.0
	1982-1993	12-year period	21.2
	1994-1997	Above-average rainfall years	19.6
	1998-2001	Drought years	23.0
Wild & Scenic	1970-1981	12-year period	0.3
	1982-1993	12-year period	0.4
	1994-1997	Above-average rainfall years	0.9
	1998-2001	Drought years	2.5
Freshwater Tributaries	1970-1981	12-year period	0.3
	1982-1993	12-year period	0.4
	1994-1997	Above-average rainfall years	0.4
	1998-2001	Drought years	0.7

*Source: Riverkeeper data from the Loxahatchee River Environmental Control District (Dent 2002, pers. comm.)

The marine/coastal segment of the river includes the habitat that is near the mouth of the Jupiter Inlet. Average salinity values range from 27.7 to 30.7 ppt for the period of record (1970-2001). Average salinity values for this segment are not significantly different for the two 12-year periods between 1970 and 1993, for the more recent above average rainfall years (1994-1997) or drought years (1998-2001) (**Table 25).** These data indicate that tidal flux, rather than freshwater inflow from upstream, is the primary factor influencing salinity concentrations at this location.

The Loxahatchee River estuary lies in the mixing zones between upstream freshwater inflows delivered by the Northwest Fork and Southwest Fork (C-18 canal) and tidal salinity provided by the Jupiter inlet. Average salinity measured in the estuary from 1970 through 1993 was between 21 and 22 ppt. As expected, the average measured salinity was lower (19.6) during above-average rainfall years (1994-1997) and slightly higher (23.0) in drought years (1998-2001), reflecting reduced and increased freshwater inputs to the estuary. These data indicate that for this area, long-term salinity values are only somewhat affected (+/-2 ppt) by annual rainfall variation in upstream basins. The primary factor influencing salinity at this location is tidal flux.

Average salinity values for the Wild & Scenic segments of the river (above river mile 6.5) range from 0.3 to 0.4 ppt during the two 12-year periods between 1970 and 1993. After 1993, salinity in this upstream segment increased in both above-average rainfall years (1994-1997, average salinity 0.9 ppt) and during drought years (1998-2001, average salinity 2.5 ppt). These data suggest that upstream portions the river may have been more impacted by saltwater during the past decade. However, the trend is uncertain because the official Wild and Scenic portion of the river includes at least one station (no. 63) that is estuarine rather than fresh water in character.

Freshwater tributaries are those creeks, streams, and canals that are direct sources of freshwater input to the Northwest Fork. These include Kitching Creek, Hobe Groves Ditch, and Cypress Creek. Average salinity values from these tributaries are comparable to those of the Wild & Scenic (freshwater) segment of the River, with values near 0.3-0.4 ppt for both 12-year periods (1970 through 1993) and the more recent above-rainfall years (1994-1997). As expected, salinity was slightly higher during drought years (1998-2001, average salinity 0.7 ppt) as compared to other time periods but were still below 1 ppt.

Soil Salinity Survey Results

Soil sampling was conducted along the Northwest Fork to investigate soil salinity concentration changes along the river and to serve as a reconnaissance effort to gain information upon which to base future sampling efforts. This analysis was also suggested by the scientific peer review panel that reviewed the 2001 Draft Technical Document. Four transects were established along the Northwest Fork in January of 2002. These four transects represented different river vegetation communities and degree of exposure to salinity from tidal influences. Location of these four transects are shown in **Figure 16.** **Chapter 4** provides a description of the methods used to collect samples and analyze data.

Results of these analyses are shown in **Table 26**. Salinity analyses conducted by measuring conductivity were similar to, but slightly higher than, the results and trends obtained from chloride analyses. Chloride proved to be a more sensitive measure of differences between sites. It should be noted that many natural waters in Florida have background conductivities in the range from 700 to 1000 µmhos/cm range. The lowest surface soil (0-0.33 m. depth) chloride concentrations were found at transect 1 (20–29 mg/L), located near river mile 11.5, the site least impacted by tidal salinity intrusion. Progressively higher chloride concentrations were detected in surface soils from transect 2 (49–95 mg/L near river mile 10.5), transect 3 (67–130 mg/L near river mile 9.9), and transect 4 (2000–3000 mg/L near river mile 6.5). At transect 4, chloride levels also varied within the vertical soil profile near the floodplain/upland ecotone and the river bank.

Table 26. Soil Salinity from Transects, Calculated from Conductivity (Cond., ppt*) and Chloride (Cl, ppt) Analyses

Collection Date	Tran-sect	Appox. River mile	Plot	Conductivity (μho/cm)	Temp. (˚C)	Salinity (Cond., ppt)	Chloride (mg/L)	Salinity (Cl, ppt)
1/22/02	1	11.5	River bed (grab)				29	0.05
1/23/02	1		River bottom	760	23		20	0.03
1/23/02	2	10.5	0-3 m	730	24	0.2	95	0.2
1/23/02	2		3-13 m	630	23	0.2	49	0.1
1/23/02	2		33-43 m	680	23	0.2	69	0.1
1/24/02	3	9.9	0-10 m	710	24	0.2	110	0.2
1/24/02	3		30-40 m	870	23	0.5	130	0.2
1/24/02	3		64-74 m				67	0.1
1/24/02	3		Floodplain/upland ecotone	680	23	0.2	81	0.1
1/24/02	4	6.5	0-10 m (0'-1')	9900	24	5.5	3000	4.9
1/24/02	4		0-10 m (1'-2')	7900	25	4	2500	4.2
1/24/02	4		0-10 m (2'-3')	6000	23	4.5	2000	3.3
1/24/02	4		45-55 m (0'-1')	6600	23	4.5	2000	3.4
1/24/02	4		45-55 m (1'-2')	6600	23	4.5	2100	3.5
1/24/02	4		45-55 m (2'-3')	5500	23	3.0	1900	3.2
1/24/02	4		95-105 m (0'-1')	8100	23	6.5	3000	4.9
1/24/02	4		95-105 m (1'-2')	7700	23	4.2	2400	4.0
1/24/02	4		95-105 m (2'-3')	9300	23	5.2	2700	4.5
1/24/02	4		155-165 m (0'-1')	10400	23	5.9	2800	4.7
1/24/02	4		155-165 m (1'-2')	8200	23	6.5	3000	4.9
1/24/02	4		155-165 m (2'-3')	9900	23	7.7	3500	5.7

*ppt = parts per thousand

Soil salinity concentrations did not reveal a well-defined gradient along the River, as was found with the chloride data. Although the plant community at transect 3 contained both freshwater and saltwater-tolerant species, soil salinity concentrations were comparable to those at unimpacted sites (transects 1 and 2). However, chloride concentrations at transect 3 (67-130 mg/L), where some red mangrove were present, were higher than in areas inhabited by strictly freshwater vegetation.These data indicate that soil chloride concentration, rather than salinity, may be a better parameter to use to characterize the salinity gradient along upstream portions of the Northwest Fork. A distinct chloride gradient was detected, associated with proximity to the Jupiter Inlet. However, elevated salinity levels were found only at transect 4 sampling sites, an area that has been impacted by elevated salinity levels for many decades.

Results from this study indicate that "background" salinity levels are very low (0.1-0.2 ppt) in unimpacted areas. This study also suggests that salinity is not retained in the soils for long periods of time. At transect 3, an area that is affected by elevated salinity conditions during droughts (e.g. 1999-2001), salinity was comparable to the pristine transects 1 and 2.

It is important to understand that the scope of this sampling effort was narrow and interpretation or application the results are limited. This preliminary study does not address potential changes in soil salinity attributed to seasonal hydrological patterns (dry season vs. wet season), droughts, duration of exposure to a salinity concentration, salinity memory (ability to retain sodium or chloride), spatial distribution along the River corridor, and vertical distribution within the soil profile (which affects shallow or deeply rooted plants differently). Results of this study can be also be used to design more comprehensive soil salinity sampling efforts.

Overall the results of this reconnaissance investigation were inconclusive. District staff had speculated that (1) soil salinity levels might serve as a reasonable indicator of past salinity conditions within the river that could be linked to the species composition of river vegetation communities, and (2) these results would show a salinity gradient from downstream to upstream areas. Even though this survey was conducted following one of the most extensive droughts recorded in South Florida, results of the survey showed no clear trend and suggest that soil salinity levels may be highly transitory in response to river flow. Based on these results, soil salinity levels may not be a good long-term indicator of stress to river plant communities.

EFFECTS OF CONSUMPTIVE USES

Three analyses were conducted to quantify the relative effects of consumptive use on surface water and ground water flows to the Loxahatchee Slough and Northwest Fork as follows:

a. A search was conducted of the District Water Use Division's geographical data base to identify all permits, wells and pumps located in the Loxahatchee watershed boundary as well as a buffer area located one-mile outside of the boundary. Results of the data base search are provided in **Appendix O,** listing the major water uses: public water suppliers (PWS), commercial and industrial (IND), golf courses (GOL), landscape irrigation (LAN) and agricultural (AGR) in the watershed and their permitted allocations.

b. In addition, District staff conducted a hydrologic analysis, using output for the Northern Palm Beach County Comprehensive Water Management Plan hydrologic model (MODFLOW), to evaluate the effects of consumptive uses within the basin on the ability to provide flows to the Loxahatchee Slough and River. These results are presented in **Appendix I.**

Based on consideration of the results of these studies and further investigation by the Water Use Division staff, the following summary of impacts was prepared:

Effects of Water Uses on Flows in the Loxahatchee River:

Based on the hydrologic and geologic characteristics of the watershed, not all water uses impact the flows in the Loxahatchee River. Uses of water that have the potential to influence Loxahatchee River flows are identified as follows:

- Direct surface water withdrawals from the River or tributaries
- Direct surface water withdrawals from the C-18 canal upstream of G-92 and S-46
- Groundwater withdrawals that lower the groundwater table under the river, its tributaries or the C-18 canal.

Review of the water use permits issued within the watershed with regard to the above criteria reveals the following:

- No water use permits have been issued that authorize surface water withdrawals directly from the River or its tributaries (Hobe Ditch, Cypress Creek or Kitching Creek)
- Three water use permits exist that authorize surface water withdrawals directly from the C-18 canal upstream of G-92 and S-46
- Two permits exist that authorize groundwater drawdowns greater than 0.1 ft beneath the Loxahatchee River or its tributaries
- Four permits exist that authorize groundwater drawdowns greater than 0.1 ft beneath the C-18 canal

Locations of these projects are shown in **Figure 22.** The remaining question is, how much do these nine projects affect the flow in the Loxahatchee River? Staff evaluated the Northern Palm Beach County groundwater model as a possible tool to quantify impacts of water use on flow rates in the River. Results of this analysis are presented in **Appendix I**. Several factors limit the ability of this model to accurately estimate surface water flows in the River.

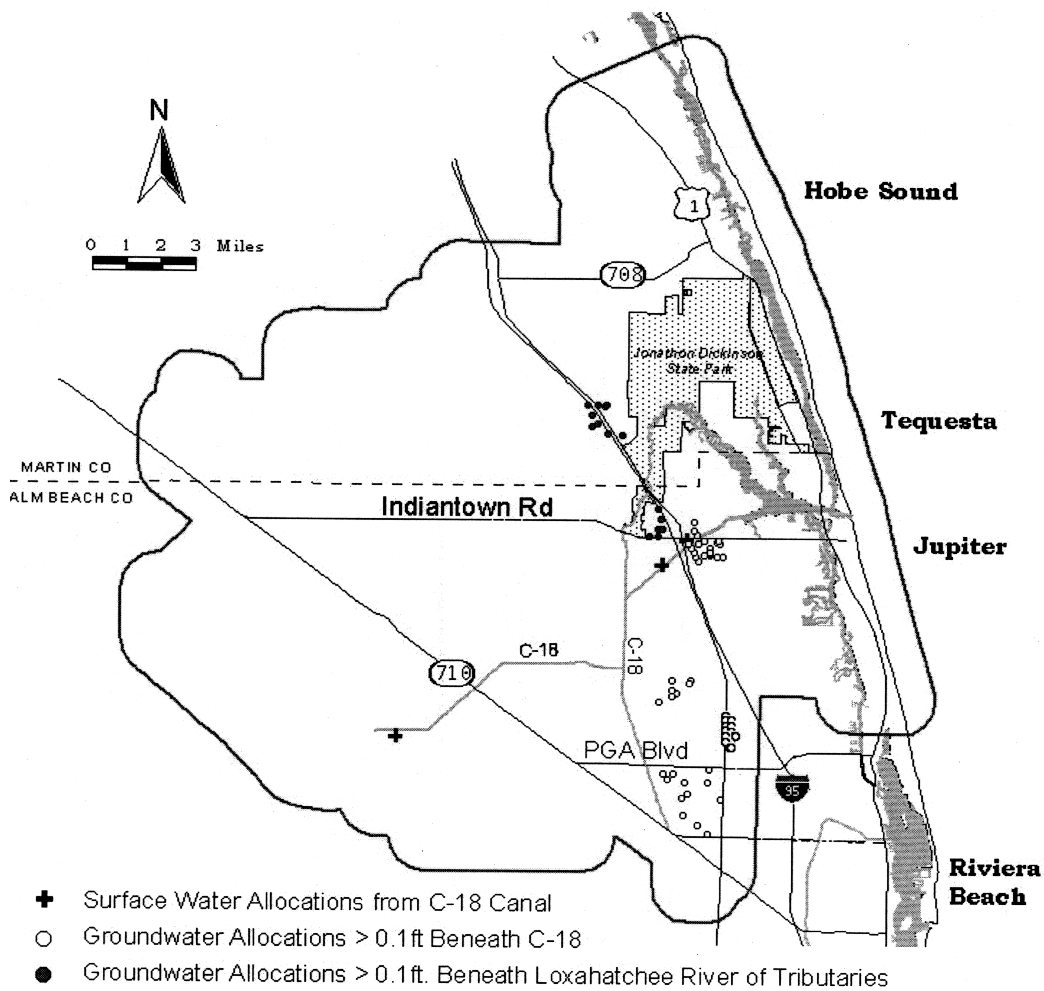


Figure 22. Location of permitted projects with potential to impact flows in the C-18 Canal, Loxahatchee River or tributaries.

- Although the groundwater model provides summaries of inflows along specific reaches, it is not capable of directly calculating surface water flow rates in canals or rivers. An effort is underway to integrate the groundwater model with a surface water model and to calibrate these models with historical data. Additional work is needed to refine the models and improve the calibration.
- The degree of hydraulic connection between the aquifer and the canal or River have not been measured directly with sufficient precision (i.e. flow rates as low as 1 cfs). The rate of leakage out of or into a canal or river is highly influenced by this factor.
- The Northern Palm Beach model only includes the southern portion of the Loxahatchee watershed and hence does not include consumptive use withdrawals in Martin County.
- More data on the timing and amounts of actual water use in the watershed are needed to accurately quantify impacts of withdrawals.

As a result of these limitations, the model has limited capability to predict changes in Loxahatchee River flows associated with consumptive use. However, a qualitative assessment of water uses in the watershed yields the following:

- The three withdrawals from the C-18 Canal include a small nursery, the Jupiter Siphon System and an agriculture property located near the Corbett Wildlife Area. The nursery is only 25 acres and has an average daily allocation of 0.01 mgd. Withdrawals from the Jupiter Siphon System are limited to those times when the stage in the C-18 Canal is greater than 14.5 ft NGVD during the dry season. As a result, the system has only operated 3 months during the last five years. The agricultural project is located approximately nine miles upstream from the G-92 structure and was modified to include water supply from an onsite mine.
- There is one agricultural project whose allocation can produce a groundwater drawdown greater than 0.1 feet beneath the Loxahatchee River and one agricultural project that has the potential for drawdowns greater than 0.1 feet beneath tributaries to the river.
  - The first project, located in Palm Beach County, has not been used for several years and has been recently acquired by another owner. This project used groundwater that was pumped from wells located adjacent to the Turnpike and moved west to the crops located next to the river. The irrigation method permitted involves a seepage/flood application that raises the groundwater table to about 18 inches below the top of the bed. This raised the water table elevation located next to the River and actually increased ground water base flow to the River when the crops were being irrigated. Changes in the type of use (such as agricultural irrigation to golf course irrigation) would require a modification of the permit.
  - The second agricultural project is located in Martin County. The allocation for this project could produce between 0.2 to 0.3 ft of drawdown beneath portions of Kitchen Creek and Cypress Creek.
- The remaining four projects that cause drawdowns under the C-18 Canal include two golf courses, the Seacoast Utilities and Town of Jupiter Utilities. The range of drawdown for each of these projects beneath portions of C-18 Canal is between 0.2 and 0.3 ft.

While the ability of existing quantitative tools to calculate the impact of consumptive uses on the flow of the Loxahatchee River is limited, based on simple flow net analysis and professional judgment indicate that the dry season impacts on flows that could potentially be delivered to the Northwest Fork are estimated to be less than 5 cfs.

BIOLOGICAL RESULTS

Importance of the Freshwater Floodplain Swamp

The freshwater floodplain swamp community located within the upstream portion of the Northwest Fork of the Loxahatchee River is an important component of the regional ecosystem. The structure of the floodplain swamp community is highly complex, comprised of low understory groundcovers and shrubs, medium height sub-canopy shrubs and hardwoods, and high canopy hardwoods, palms and bald cypress, including a number of cypress tress within the 300-500 year old range. The high canopy supports a wide variety of epiphytic plants such as ferns, bromeliads and orchids. The floodplain swamp community supports a number of important water resource functions for the ecosystem as follows: (1) provides leaf litter and organic detritus that are the basis of the food chain for upstream river system as well as the downstream estuary; (2) helps to stabilize the river shoreline and soils to prevent erosion; (3) provides specialized habitat for many plant and animal species, a number of which are rare, threatened or endangered; (4) maintains and protects water quality in the River; and (5) supports a diverse population of animals, including many that also utilize the surrounding upland and estuarine habitats. Wetland forest communities similar to those found along the upper reaches of the Loxahatchee River support both high wildlife density and diversity (Ewel 1990b).

In downstream reaches of the river, diversity of floodplain vegetation is reduced sharply by the influence of salt water. Mangroves are specifically adapted to live in saline environments, and because of their size, they tend to shade out other competing salt-tolerant wetland species such as cordgrass (*Spartina* spp.). Over time mangrove communities become essentially monocultures and hence have very low vascular plant species diversity. This low vascular plant species diversity, however, is compensated by the fact that mangroves produce large amounts of leaf litter that is used extensively by aquatic organisms as a food source and that many brackish water and marine species of algae and animals thrive in the extensive network of mangrove proproots.

The long-term decline in the distribution and health of the floodplain swamp community within the mid to upstream portion of the Northwest Fork have been linked to periods of saltwater intrusion during low rainfall periods (Rodis 1973, Alexander and Crook 1975, Russell and McPherson 1984). These periodic episodes of increased salinity appear to be correlated with past hydrologic alterations of the river and its upstream watershed, as well as (potentially) long-term changes in rainfall patterns, climate, and sea level rise. These alterations most notably include the following: (a) the permanent opening of the Jupiter inlet in 1947, (b) dredging activities conducted within the estuary to improve navigation, and (c) construction of the C-18 Canal in 1957-58 which diverted freshwater flows away from the Northwest Fork to the

Southwest Fork. Combined, all of these factors have resulted in reducing the amount freshwater flow delivered to River during dry periods and have increased the frequency that the floodplain swamp has been exposed to increased saltwater concentrations. Sufficient fresh water needs to be delivered to the river during dry periods to protect the remaining floodplain swamp community, a Valued Ecosystem Component, from further degradation and loss of natural function.

Because of its ecological importance to the region and surrounding communities, the focus of this report was on establishment of MFL technical criteria for the Northwest Fork to protect the remaining floodplain swamp community against significant harm. Due the lack of recent flow or biological data from the North Fork, and the highly altered nature of the Southwest Fork, these two arms of the Loxahatchee Estuary were not considered for MFL establishment at this time, but may be considered in the future as part of FDEP's MFL Priority List update.

The Effects of Salinity on Cypress Trees

An issue of primary concern during the preparation and review of the previous version of this report (SFWMD 2001) was the effect of salinity on bald cypress trees (*taxodium distichum*). Because a close relationship between salinity levels and mortality of bald cypress could not be established, SFWMD scientists investigated the methods that are used in the present study, which involve an assemblage of freshwater swamp species. However, since cypress trees are a dominant component in the "Wild" portion of the Northwest Fork, effects of salt water on this species are still a primary concern. In addition, the results of this investigation reveal trends and relationships that apply to other predominantly freshwater species. A more detailed treatment of this subject is provided in **Appendix A**.

Concepts to be Considered

Recent changes in the historic distribution of cypress trees along the Northwest fork of the Loxahatchee River have been well documented (Alexander and Crook, 1975; Rodis 1973; SFWMD, 2002). The mechanisms related to these changes are not entirely understood, but there is a strong relationship between cypress tree die off and increasing levels of salinity within the river (Alexander and Crook, 1975; Rodis 1973). To understand the effects of elevated salinity on cypress trees, two salinity thresholds need to be considered: acute and chronic.

The acute threshold is the salinity level where trees are injured or killed after one exposure event. This may occur during a severe drought or from a surge of sea water pushed upstream during a storm event. Under such conditions, areas that are primarily freshwater systems become inundated with saltwater. As the magnitude of salinity and duration of exposure increase, the potential for injury or death to cypress increases. Effects are often visible within a short time from exposure (i.e. weeks to months).

The chronic threshold is the salinity level where bald cypress are injured or killed after long-term exposure. Unlike the transient drought or storm surge event described above, this threshold is characterized by continuous (or nearly so) exposure to low-level saline conditions. This exposure has the effect of crippling vital biological functions of the tree which can lead to developmental deformities, slowed growth rates, reduced canopy or leaf area, increased parasitism, and perhaps eventual death. Cypress suffering from salt stress are less disease resistant, less competitive ecologically, and less capable of producing viable offspring that are capable of regenerating the forest. Effects are usually only visible after a long period of exposure (i.e. months to years). The chronic threshold level to be lower than the acute threshold level. Furthermore, differences between mature tree and seedling thresholds are may be significant.

Of primary consideration in protection of the riverine swamp community is to provide of sufficient freshwater flow to prevent saline water from penetrating upstream. As more water flows through the river, the saltwater interface is pushed further downstream towards the ocean. Another important consideration is the effect of groundwater discharges and seeps to the river floodplain. Groundwater levels in areas adjacent to the river also influence the inland extent of saltwater intrusion. Typically, the depth at which saltwater intrusion occurs is directly related to the elevation of groundwater as shown in **Figure 23.**

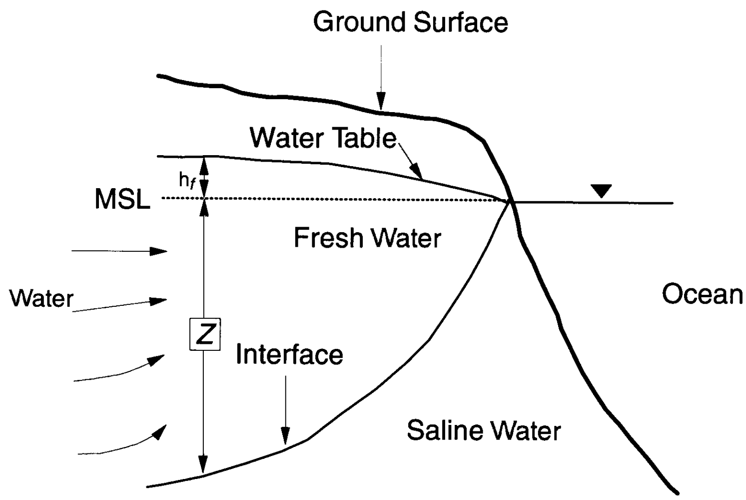


Figure 23. Relationship between water table elevation (h_f) and the depth below ground at which saltwater intrusion occurs (Z). As ground water level increases, the depth at which intrusion occurs also increases.

Plant physiology, especially relative to root development, is another important factor that determines the response of a species to salinity flux. The depth and extent of root systems, and proximity to the edge of the floodplain both influence the potential for impact from elevated saline conditions. Tropical tree species (e.g. mangroves) typically develop shallow networks of roots near the soil surface. These species are more influenced by surface water conditions and variations. Temperate and subtropical tree species, including bald cypress, tend to be more deeply rooted and are more influenced by subsurface water quality. Established, mature trees near the edge of the floodplain are less affected by river salinity variations, since groundwater seepage from the uplands can maintain a head of freshwater against the salt water influx. Young saplings near the river channel are more likely to be damaged by periods of increased salinity. Other factors affecting the depth of root penetration include the presence of a hardpan or rock layer and the existence of anoxic conditions.

Literature Review

Rodis (1973) published his observations of the effects of elevated salinity on the cypress forests of the Loxahatchee River. He concluded that a minimum flow of 50 cfs would be necessary to maintain a 2 ppt salinity wedge north of the Lainhart Dam. The biological basis of this criterion is not clear.

There currently are no salinity threshold studies of cypress trees in the Loxahatchee River Basin. Pezeshki et al. (1987), Allen et al. (1994) and Krauss et al. (1999) performed experiments on bald cypress seedlings from Louisiana and found that acute salinity toxicity effects occur above 2 ppt salinity. None of these experiments adequately covered the salinity range between 0 and 2 ppt. Therefore, a target cannot be determined from these studies for the acute salinity threshold for mature trees or for the chronic threshold for either seedlings or mature trees.

There are apparently no data to determine the relationships among groundwater levels, extent of saltwater penetration from the river to the edge of the floodplain, and depth below ground where saltwater occurs. Several studies have been initiated to determine the salt content and salt gradients in floodplain soils and shallow ground water, but results of these investigations have not been published (Roberts, personal communication; Worth, personal communication). Similarly, there are no data from the Loxahatchee River cypress community concerning the depth of the root zone or the relationship between cypress tree size and depth of root penetration.

Conclusions and Recommendations

- There have been no studies conducted to investigate the relationship between the extent of saltwater migration up the Loxahatchee River and the dieback of bald cypress trees in the floodplain.
- However indirect evidence and observations by a number of authors, indicates that there is a strong correlation between upstream saltwater encroachment and extensive dieoff of bald cypress, replacement of freshwater swamp by mangroves and other salt-tolerant species, and the current distribution of a “stressed” freshwater floodplain vegetation community in which cypress trees appear to be stunted and chlorotic.
- Maintenance of a viable cypress community in the Loxahatchee River floodplain needs to be based on consideration of both acute and chronic effects of salinity exposure.
- Results of studies conducted on Louisiana bald cypress seedlings suggest that exposure to a 2 ppt salinity concentration may lead to symptoms of acute exposure, such as seedling injury or death (Rodis, 1973). However, there are no indications from the literature on salinity levels that lead to stress or mortality of seedlings in the long term, or for mature trees.
- Additional research is needed to determine effects of salinity on bald cypress trees of different sizes, effects of groundwater interactions, salt content of floodplain soils at different depths and distances from the river, and the depth of cypress root penetration.

River Vegetation Survey Results

In order to develop a database that could be used to analyze river vegetation/salinity trends, a survey was conducted of existing vegetation communities along the river.

Semi-quantitative Survey

A semi-quantitative survey was conducted in November of 2000 and December of 2001 to examine community-based vegetation changes along the Northwest Fork of the Loxahatchee River. A total of 23 sites were surveyed as shown in **Figure 16, Chapter 4.** Measured vegetation parameters included species composition, and abundance. These data were then correlated with distance (in terms of river miles) upstream from the Jupiter Inlet, the primary source of salinity to the river. An additional 10 sites were surveyed in Kitching Creek.

Results from the November 2000 survey of 16 sites identified 35 species of vascular plants from sites examined in the floodplain of the Northwest Fork (**Table 27**). Analysis of these data showed that the total number of plant (vascular macrophytes) species decreases dramatically from upstream freshwater habitats to downstream saltwater-dominated areas **(Figure 24).** These data indicate that a) observed vegetation trends were consistent in both the 2000 and 2001 surveys; b) the number of species increased as a function of distance from the inlet; c) the trend was consistent in both the Northwest Fork and Kitching Creek, and d) the number of species was correlated with salinity.

Results of the semi-quantitative survey also showed that bald cypress and cabbage palm, as single species, appear to tolerate a wider range of salinity conditions within the river corridor than a number of other common floodplain swamp species. **Table 28** shows the distribution and abundance of common tree species that characterize the river's floodplain swamp forest.

This relationship can be described by a linear equation ($R^2 = 0.93$) with upper and lower limits near 35 and 5 species. A similar trend was observed along Kitching Creek for data collected during the same period. These results suggest that the distribution of freshwater vegetation along the river is strongly correlated with the existing salinity gradient.

As shown in **Table 28,** the distribution and abundance of red maple, dahoon holly, pop ash, pond apple red bay, and Virginia willow all appear to be impacted within a very short segment of the river as compared to bald cypress or cabbage palm. As a group, these six freshwater species were limited in their distribution along the river suggesting that they may be more sensitive to long-term changes in salinity as compared to bald cypress, cabbage palm or red mangrove communities.

Table 27. Plant species collected in the Northwest Fork floodplain during quantitative and semiquantitative sampling periods, November, 2000 and January 2001

Scientific Name	Common Name	Scientific Name	Common Name
Acer rubrum	Red maple	*Osmunda regahis*	Royal fern
Annona glabra	Pond apple	*Persea borbonia*	Red bay
Aster carollniana	Carolina aster	*Phlebodium aureum*	Golden polypody
Baccaris sp.	Saltbush	*Pleopeltis polypodioides*	Resurrection fern
Blechnum serrulatum	Swamp fern	*Polygonum sp.*	Swamp smartweed
Boehmeria cylindrica	False nellie	*Pontederia cordata*	Pickerelweed
Catya aquatica	Water hickory	*Ouercus laurifolia*	Laurel oak
Crinum americanum	String lily	*Sabal palmetto*	Cabbage palm
Ficus aurea	Golden fig	*Sahix carohiniana*	Swamp willow
Fraxinus caroliniana	Pop ash	*Smilax sp.*	Greenbriar
Hydrocotyl sp.	Water pennywort	*Taxodium distichum*	Baldcypress
Hyptis sp.		*Tihlandsia balbisiana*	Air plant
hex cassine	Dahoon	*Tihlandsia fasciculata*	Stiff-leafed wild pine
Ipomoea alba	Moon flower	*Tihlandsia recurvata*	Ball moss
Itea virginica	Virginia witlow	*Tihlandsia setaceae*	Air plant
Ludwigia repens	Creeping primrose willow	*Tillandsia usneoides*	Spanish moss
Mikania scandens	Climbing hempvine	*Toxicodendron radicans*	Poison ivy
Nephrolepis sp.	Wild Boston fern		

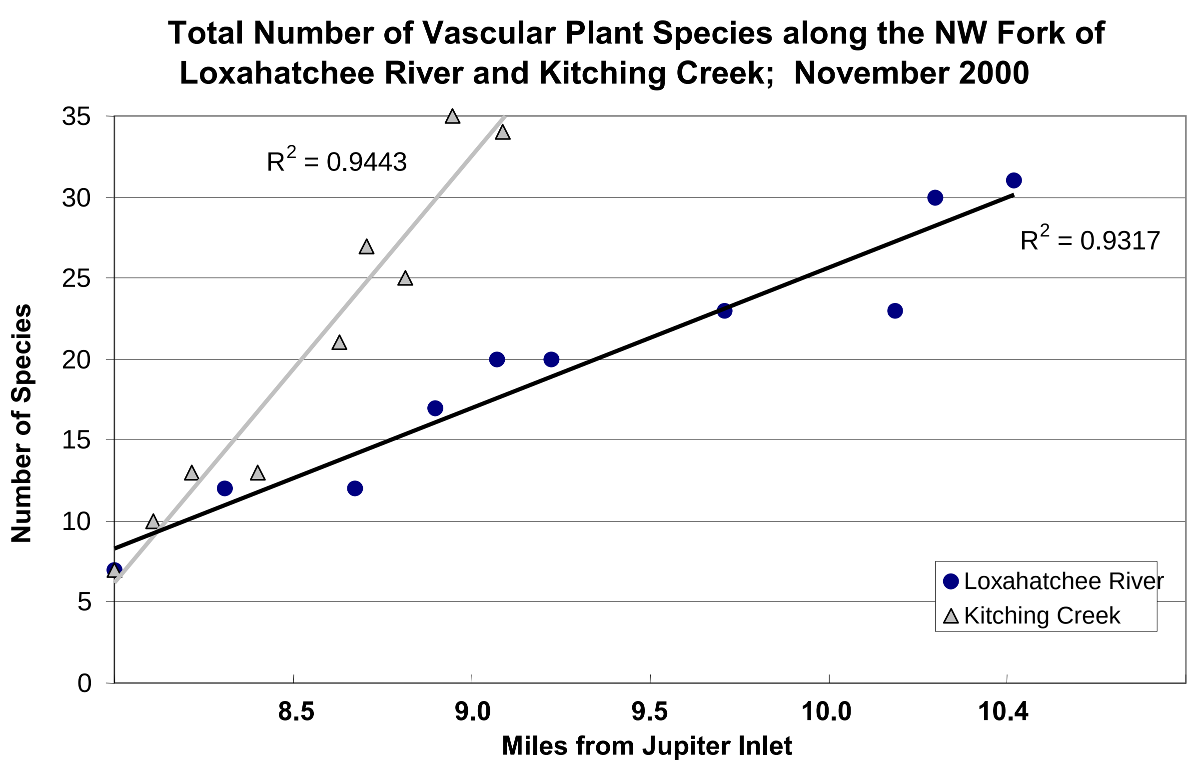


Figure 24. Number of Observed Vascular Plant Species versus river mile, Northwest Fork of the Loxahatchee River and Kitching Creek (November 2000).

Table 28. Abundance Index*: Results of a semiquantitative vegetation survey at river vegetation sampling locations, Northwest Fork, Loxahatchee River (November 2000/December 2001).

Station Name	7A	7B	7C	V7	8A	8B	V6	8C	V5	8D	9A	9B	V4	9C	V3	10A	10B	V2	10C	V1
River mile	7.3	7.5	7.8	7.95	8.1	8.4	8.55	8.7	8.8	8.9	9.1	9.2	9.3	9.7	9.9	10.1	10.2	10.3	10.4	10.6
bald cypress	0	0	1	1	1	2	1	2	2	3.5	3	3	2	4	4	4	4	4	4	4
cabbage palm	2.5	3	3.5	2	4	3	2	3.5	3.5	3.5	4	3	3	3	3	3	3	2.5	2	3
red mangrove	4	4	4	4	4	4	4	4	4	4	4	4	3	2.5	2	0	0	1	0	0
pond apple	0	0	0	1	0	0	0	3	2	3	3	3	1	3	3.5	3.5	3	3	3.5	3.5
dahoon holly	0	0	0	0	0	0	0	0	0	1	1	1	1	1	2	2	2	3.5	3	2
pop ash	0	0	0	0	0	0	0	0	0	0	0	1	0	2	2	2	2	2	2	2.5
red maple	0	0	0	0	0	0	0	0	0	1	1	1	0	2	1	3	3	3	3.5	3.5
Virginia willow	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	2.5	2	3.5
red bay	0	0	0	0	0	0	0	0	0	0	0	0	1.5	0	0	0	1.5	1	0	1.5

* Abundance Index
4 = Highly abundant or dense population (>75% cover), a dominant component of the plant community
3 = Common; widespread and of moderate density but not a dominant component of the plant community
2 = Sparse; widespread and of low density or restricted to localized populations
1 = Two or less individuals; rare
0 = Species not present

Table 29 provides a list of these six key species and their salinity tolerances obtained from a review of the literature. The river survey data also indicates that bald cypress, used as a single indicator species, is not the most sensitive indicator of salinity stress within the Northwest Fork of the Loxahatchee River. Based on these relationships, District staff chose the following six species (red maple, pop ash, red bay, Virginia willow, dahoon holly, and pond apple) as the selected "valued ecosystem component" (VEC) for the Northwest Fork (see later section of this report entitled, *Proposed VEC for the Northwest Fork of the Loxahatchee River*). In order for a species to maintain itself at a particular location, not only must the plants (trees) survive, but they must also be able to replace themselves over time by successful reproduction. These plants must thus be able to produce viable seeds, the seeds must germinate, and seedlings and saplings must survive to an adult seed-producing stage. These various life stages may have different salinity tolerances than the adults.

Table 29. Key species identified along the Northwest Fork and their salinity tolerances.

Species	Saltwater Tolerance
Selected "KEY" Species	
Red maple *(Acer rubrum)*	Freshwater[a]
Pop ash (*Fraxinus caroliniana*)	Freshwater[a]
Virginia willow (*Itea virginica*)	Freshwater[a]
Dahoon holly (*Ilex cassine*)	Freshwater[a]
Red Bay (*Persea borbonia*)	Freshwater[a]
Pond apple (*Annona glabra*)	Freshwater[a]
Other Dominant River Vegetation Species	
Bald cypress (*Taxodium distichum*)	Freshwater to slight salt tolerance[c]
Cabbage palm (*Sabal palmetto*)	Freshwater to slight salt tolerance[b]
Red mangrove (*Rhizophora mangle*)	Salt tolerant[a]

[a] see Tobe, et al. 1998.
[b] Cabbage palm is generally associated with freshwater and coastal swamps
[c] see Allen 1994; Allen et al. 1994, 1997; Conner 1992; Javanshir & Ewel 1993, Pezeshki et al. 1986, 1987, 1990, 1995.

A second semi-quantitative survey was repeated in December 2001 at seven additional sites**.** These results showed a similar trend as reported for the previous survey, with a R^2 of 0.97 reported (**Figure 25**), but exhibited higher total number of species.

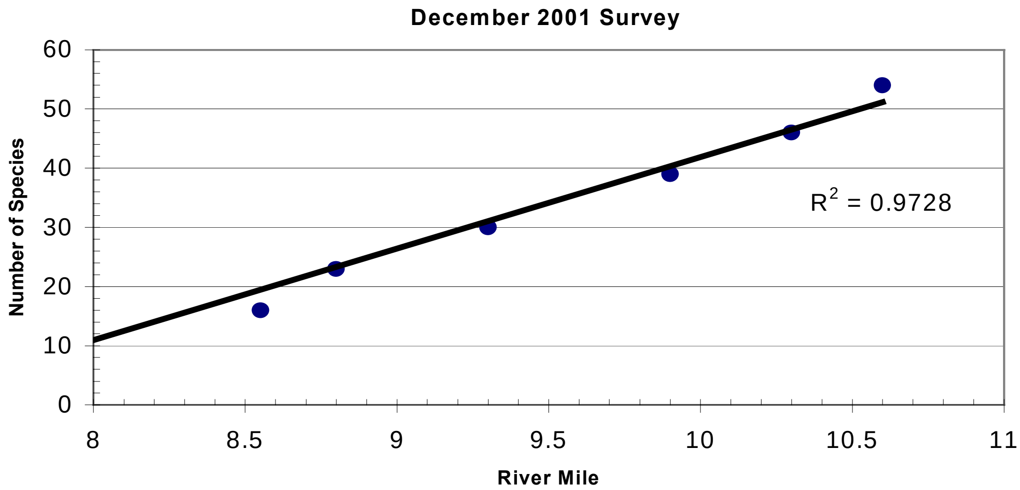


Figure 25. Relationship between total number of vascular plant species and location (river mile) along the Northwest Fork of the Loxahatchee River (December 2001 survey)

Differences in the total number of species observed could be accounted for by differences in rainfall patterns and the number of herbaceous species recorded between the two surveys. Although more species were reported than during the 2000 survey, as perhaps would be expected after a major drought period, the significant positive trend shows that total number of floodplain vascular plant species increases with distance from the inlet and decreases at those stations (with observed higher salinity values) located nearer to the inlet. This relationship provides further evidence that salinity plays an important role in regulating plant community species composition and distribution along the Northwest Fork of the Loxahatchee River

Quantitative Survey

In January 2002, a quantitative vegetation survey was conducted along the Northwest Fork. In this survey District staff selected 9 of the original 23 vegetation sampling sites recording both plant community-based and species-based information. **Figure 16 (Chapter 4)** shows the location of the nine quantitative vegetation-sampling sites that were resurveyed in January 2002.

Eight of these sites (sites V7, 8B, 8D, 9A, 9B, 9C, 10B and V1) were used to compare findings against previously collected semi-quantitative data. Three sites (V1, V3, and V7) were used as model verification sites (**Figure 16, Chapter 4**). The following community-based and species based parameters were measured at each site:

- Presence or absence of selected VEC species
- Number of individuals of VEC species
- Age class of VEC species (mature tree, sapling, seedling, and stump spouts)
- Tree height of VEC species
- Trunk circumference at breast height of VEC species

- Canopy diameter of VEC species

Details regarding sampling methods for the vegetation surveys and field data from vegetation surveys are presented in **Appendix C** of this report.

Vegetation Community Measurements

Number of Adults

Table 30 provides a summary of the total number of adult tree VEC species present at each quantitative vegetation transect sampling site.

Table 30. Number of adults and saplings of selected tree species recorded during the January 2002 quantitative vegetation survey, at eight locations along Northwest Fork.

	Station Name	V1	10B	9C	9B	9A	8C	8B	V7
	River mile	10.6	10.2	9.7	9.2	9.1	8.7	8.4	7.95
VEC Species	popash	39	40	35	2	1	0	0	0
	red bay	4	7	6	0	0	0	0	0
	dahoon holly	1	20	5	2	0	0	0	0
	Virginia willow	123	47	35	0	1	0	0	0
	red maple	22	16	10	0	0	0	0	0
	pond apple	17	52	42	13	24	0	0	0
Other Species	bald cypress	22	58	33	4	4	4	3	0
	cabbage palm	19	31	43	33	13	11	47	46
	red mangrove	0	1	18	200*	200*	180	200*	200*

* Due to the large number of red mangrove trees present at sites V7 – 9B, values were estimated

Results show that under current conditions, downstream of river mile 9.1 the majority the six VEC species have been eliminated from the floodplain swamp. At river mile 9.2 only three adult species are present; while upstream of at river miles 9.7, 10.2 and 10.6 all six VEC species are present. These results suggest that major changes have occurred to those vegetation communities located downstream of river mile 9.2.

Tree Height and Trunk Diameter

Measurement of physical features such as mean trunk diameter (DBH) and mean tree height showed a similar trend to that shown by the numbers of adults of each species present. As one moves downstream from river miles 10.6 to 9.1 there is a trend of both reduced tree height and trunk diameter suggesting these communities have been physiologically stressed due to periodic exposure to increased salinity levels in areas nearer to the Jupiter inlet (**Table 31**).

Number of Saplings and Seedlings Present

Observations of the number of saplings or seedlings present at each site were important for determining if the community is reproducing and sustainable (**Table 32**). The presence or absence of saplings or seedlings was also considered a more sensitive indicator of the degree that saltwater may impact the community over time. That is, under low salinity concentrations it may be possible to sustain an adult tree, however seedlings or very young tress may not be able to survive.

Table 31. Mean trunk diameter (DBH) and mean tree height of adults at eight river vegetation sampling locations, Northwest Fork of the Loxahatchee River (January 2002)

Station Name	**V1**	**10B**	**9C**	**9B**	**9A**	**8C**	**8B**	**V7**
River mile	**10.6**	**10.2**	**9.7**	**9.2**	**9.1**	**8.7**	**8.4**	**7.95**
Mean Trunk Diameter/Tree Height (in feet)								
VEC Species								
Pond apple	1.8/24	1.0/20	0.4/15	0.3/14	0.5/9	0/0	0/0	0/0
dahoon holly	0.6/28	0.3/17	0.1/12	0.2/13	0/0	0/0	0/0	0/0
pop ash	0.9/19	0.5/19	0.2/13	0.3/14	0.3/11	0/0	0/0	0/0
red maple	1.4/29	0.7/22	0.4/24	0/0	0/0	0/0	0/0	0/0
red bay	0.1/18	0.2/20	0.1/8	0/0	0/0	0/0	0/0	0/0
Other Species								
bald cypress	3.2/43	0.7/23	0.9/32	NA/27	0.3/14	1.0/17	NA/25	0/0
cabbage palm	NA/25	NA/30	NA/24	NA/19	NA/14	NA/11	NA/19	NA/15
red mangrove	0/0	NA/12	NA/9	NA/14	NA/9	NA/9	NA/8	NA/8

NA = data not available; Calculations based on measurement of adult species;
Note: Virginia willow is a shrub and therefore was not measured using the above methods.

Table 32. Number of saplings and seedlings present at eight river vegetation sampling locations, Northwest Fork of the Loxahatchee River (January 2002)

Station name	**V1**	**10B**	**9C**	**9B**	**9A**	**8C**	**8B**	**V7**
River mile	**10.6**	**10.2**	**9.7**	**9.2**	**9.1**	**8.7**	**8.4**	**7.95**
Number of Seedlings/Saplings Present								
VEC Species								
pond apple	0/1	0/10	1/3	0/0	1/0	0/0	0/0	0/0
dahoon holly	0/0	7/0	1/0	0/0	0/0	0/0	0/0	0/0
pop ash	6/13	5/3	3/0	0/0	1/0	0/0	0/0	0/0
red maple	1/44	5/38	0/0	0/0	0/0	0/0	0/0	0/0
virginia willow	NA /63	NA /20	NA /9	NA /0	NA /1	NA /0	NA /0	NA/0
Red bay	1/1	3/11	4/0	0/0	0/0	0/0	0/0	0/0
Other Species								
bald cypress	1/0	24/7	5/0	0/0	0/0	0/0	0/0	0/0
cabbage palm	0/0	1/0	0/0	0/0	0/0	0/0	0/0	0/0
red mangrove	0/0	0/0	2/27	NA	NA	NA	NA	NA

NA = data not available, transect inaccessible.

Results of the vegetation survey show that very few VEC saplings or seedlings are present downstream of river mile 9.2, suggesting that this community can no longer reproduce, is not sustainable, and thus has experienced significant harm (**Table 31**). At river mile 9.7, the number of VEC species saplings and seedlings appear to be reduced in comparison to upstream areas, indicating that this section of the river is currently stressed by periodic exposure to low salinity levels.

Canopy Cover

A primary aspect of forest structure that plays an important role in the ecology of the floodplain swamp is the canopy. Bald cypress' tendency to dominate wetland forests is largely due to their ability to form a high closed canopy, which is particularly evident during the growing season. Within the Wild and Scenic portion of the Loxahatchee River the floodplain swamp canopy supports a large array of air plants, bromeliads, and orchids, many of which are federally threatened or endangered species (FDEP and SFWMD 2000). The canopy plays a critical role in the life cycles of many birds, reptiles, and insects. The canopy also regulates the microclimate of the forest, controlling humidity, light quality, rainfall distribution and other physical parameters that can have profound influences on plant growth.

In this study, tree canopy areas within various tree height classes were calculated from tree canopy diameter measurements (see **Appendix C** for methods). **Figure 26** shows striking changes in canopy cover area for the six selected VEC species associated with distance (river mile) upstream from the Jupiter Inlet. Major changes in canopy cover were measured between river miles 9.7 and 9.2 indicating that a physical change has occurred to the structure of the floodplain swamp forest structure between these two sites. Upstream (at river miles 10.2 and 10.6), the floodplain forest appears as a complex structure with a high canopy dominated by bald cypress (between 35–60 ft. in height) and a secondary canopy dominated by mixed hardwoods, bald cypress, and pond apple (between 15-30 ft. in height) **(Figure 26).**

Some shrubby species are found below the secondary canopy, at less than 10 ft in height. A short distance downstream at river mile 9.7, the structure of floodplain forest shows a decrease in the area of the high canopy strata. At river mile 9.2 the high canopy has been virtually eliminated and has been replaced by a low canopy dominated by red mangroves approximately 15 ft above the ground surface. These changes in forest structure can have profound effects on microclimate, ecological function, and species composition (both flora and fauna) of the floodplain swamp forest.

Historical Changes in River Vegetation Communities

Aerial Photography Survey Results

District staff used existing historical aerial photography to compare changes in the distribution and abundance of vegetation communities along the floodplains of the Northwest Fork through time. Black and white aerial photos taken in 1940 were compared to color infrared photography taken in 1985 and 1995 between river miles 4.5 and 11.2 to quantify changes in the coverage of major vegetative communities. The focus of this investigation was to assess changes in the distribution and abundance of freshwater hardwood and cypress communities and salt-tolerant mangrove communities along the river between these time periods.

For comparison purposes, total acreages of vegetation types were analyzed within six segments of the 1940 and 1995 coverages. For a six-decade sequence, black and white photographs from 1940, 1953, 1964 and 1979 were digitized and compared to infrared photography from 1985 and 1995 between river miles 6.6 and 8.9. To further validate vegetative signatures, District staff re-examined several sites along the Northwest Fork that were originally documented by Alexander and Crook (1975) during their investigation of long-term changes in South Florida vegetation communities. The purpose of this work was to document changes in vegetative cover through time and correlate these changes to major hydrologic events in the watershed.

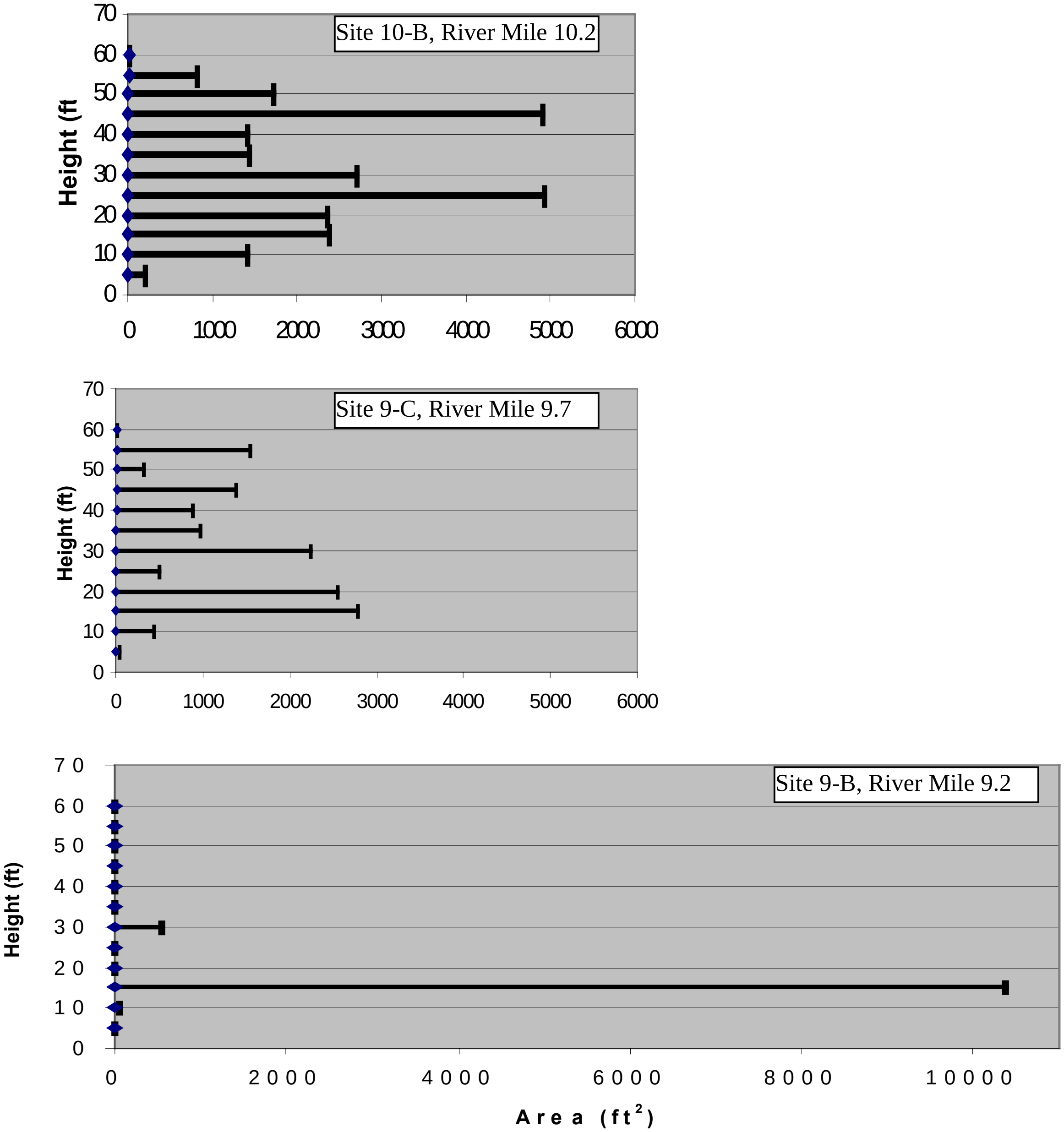


Figure 26. Total Forest Canopy Area Within Height Classes for three sites along the Northwest Fork of the Loxahatchee River

The 1940 aerial black and white photos were obtained from the National Archives (College Park, Md.) while the 1953, 1964 and 1979 photographs were obtained from the U.S. Department of Agriculture, Consolidated Farms Service Agency in Salt Lake City, Utah. The 1985 color infrared photographs were obtained from a special flight conducted for SFWMD over Lake Okeechobee and portions of the Loxahatchee River Watershed. The 1995 color infrared Digital Ortho Quad photographs were obtained from National Aerial Photography Program. Groundtruthing and field observations were conducted by District staff to validate signatures of current plant communities found along the river floodplain. **Appendix B** provides a detailed summary of the methods, results, and river vegetation maps developed during this investigation.

Historically, the Loxahatchee River watershed consisted primarily of coastal hammock, pine flatwoods, seasonal ponds and prairies, freshwater swamp, and hardwood forests. Much of this vegetation remains today due to earlier military and agricultural uses. Subsequent land use changes have created large tracts of public conservation and recreation and agricultural lands, and low-density zoning (5-acre to 10-acre ranchettes). The Northwest Fork has been provided with additional protection as portions of this water body have been designated as a federal Wild and Scenic River. The oldest municipality is the Town of Jupiter, which was incorporated in 1925. The neighboring municipalities of Juno Beach, Jupiter Inlet Colony, Jupiter Island, Palm Beach Gardens, and Tequesta were all incorporated during the 1950s (**Table B-1, Appendix B**). Today the primary land uses are public conservation and recreation, agriculture, and residential.

1940 Vegetative Cover

Figure B-3 and Table B-3 (Appendix B) provide summaries of the major vegetation communities found along the Northwest Fork and adjacent areas (including the floodplain, wetlands in Jonathan Dickinson State Park [Wilson Creek] and some uplands) in 1940, based on a review of historical black and white aerial photographs. **Table 33** summarizes the coverage (in acres) and changes in coverage of each community type for 1940, 1985 and 1995.

Table 33. Interpreted vegetation coverages (acres) for 1940, 1985 and 1995 for the Northwest Fork and adjacent areas, from river miles 4.5 to 11.2, based on aerial photography.

VEGETATION	1940 Coverage	1985 Coverage	1995 Coverage	Acres Difference 1940-1985	Acres Difference 1940-1995	Acres Difference 1985-1995
Freshwater Plant Communities						
Swamp Hardwood Cypress Stream Swamp**	467	339	326	-128	-142	-13
Inland Ponds and Sloughs	59	39	39	-20	-20	0
Freshwater Marsh	NA	5	2	NA	NA	-3
Cabbage Palm	3	7	4	+4	+1	-3
Category Total	***529***	***390***	***371***	***-139***	***-158***	***-19***
Saltwater Tolerant Plant Communities						
Mangrove	163	163	155	-2	-11	-9
Other						
Disturbed or Cleared Lands	27	84	84	+57	+57	-0
TOTAL	**720**	**635**	**607**	**-85**	**-113**	**-28**

*Coverage in acres

** Since swamp hardwood, stream swamp and cypress communities could not be accurately distinguished in the 1940's photographs, these subcategories were combined to provide a basis for comparison.

Results show that the watershed was relatively undeveloped in 1940. The most obvious features are the abundance of wetlands associated with sloughs and wet prairies and the lack of urban development throughout most of the watershed.

According to the 1940 U.S. Census, the Town of Jupiter contained 215 residents (**Table B-1, Appendix B**). Interstate 95 and the Florida Turnpike had not yet been constructed. The major roads at that time were Center Street, State Road 706 (Indiantown Road), State Road 710 (Beeline Highway), U.S. Highway 1, State Road 708 (Bridge Road) and Northlake Boulevard. Although the C-18 Canal had not yet been constructed, there was evidence of ditching from the River to the Loxahatchee and Hungryland Sloughs. The Jupiter Inlet was open in the 1940 photograph, but the presence of sandbars probably reduced the amount of saltwater coming in during high tides. The inlet was not permanently stabilized for navigation until 1947. On the Northwest Fork, tides, winds and periodic storm events may have had sufficient effects upstream past the mouth of Kitching Creek to promote growth of what appear on the photographs to be mangroves along the northern river bank, extending upstream to river mile 7.8. In **Figure B-5 of Appendix B**, the 1940's distribution of the swamp hardwood (dominated by cypress) community is color-coded green, while mangroves are color-coded orange. This coverage represents our earliest photographic record of the distribution of mangroves and freshwater communities. Freshwater communities extend downstream as far as river mile 5.8.

The three main tributaries of the river and the surrounding lands feed into the northern loop of the river, while the uplands and sloughs provide a network of interconnecting lakes, ponds and wetlands (**Figure B-1, Appendix B**) that feed into these tributaries and provide groundwater recharge. There are extensive wetlands (prairies and four major sloughs) between Kitching Creek, the North Fork, and Bridge Road at the north end of Jonathan Dickinson State Park in Martin County. Two of the sloughs appear to connect the North and Northwest Forks. These four areas historically may have provided sources of fresh surface and ground water flows to the river, but only Wilson Creek is still connected to the river today. Other visible hydrologic characteristics identified in the 1940 photographs included the following (refer to **Figure B-1, Appendix B** for location of features):

- On the Northwest Fork, Hobe Grove Ditch was not present in 1940, but Moonshine Creek was apparent and drained a wetland slough to the north
- No citrus was grown near the river as it is today, but there was extensive land clearing north of SR 706 on the east side of the Northwest Fork perhaps for agriculture
- A wetland slough connected Jones Creek to Lake Worth Creek (in the vicinity of what is today Frenchmen's Creek)
- Jones and Sims Creeks were lined with mangroves south of SR#706
- The Southwest Fork was a meandering creek that appeared to be dominated by mangroves
- The Southwest Fork/Limestone Creek had been ditched but not channelized

- Mangroves bordered the North Fork and transitioned into freshwater vegetation in the vicinity of today's park boundary (north of the Girl Scout Camp). The floodplain was very narrow in the mangrove areas
- There were very few mangrove islands in the embayment area
- Spoil mounds were evident along the Lake Worth Creek and the lower Indian River Lagoon from the dredging of the Atlantic Intracoastal Waterway channel

An estimate of the location of Interstate 95 and the Florida Turnpike was made to define the southern boundary of the study area in the 1940 photo. Unlike the clarity of later black and white infrared photography that was taken in the 1950s and 1960s, it was difficult to identify plant species other than cypress and cabbage palm within the freshwater communities. In addition, the 1940 photographs were taken during August, when all trees would have full canopies. Most subsequent aerial photographs were taken during the winter months when trees, like cypress, are dormant and very distinguishable. Thus in **Table 32,** total acreage of cypress was combined with other freshwater vegetation to compare 1940 with 1985 and 1995 coverages.

In this study, the category of cypress represents a community dominated by cypress (more than 50% coverage) but that also may contain red maple, pond apple, pop ash, water hickory, laurel oak, and bay trees. The category of stream swamp represents a freshwater community of primarily mixed hardwoods with cypress (present but not dominant). Cabbage palms, which are normally associated with upland communities, are found at tidally inundated to seldomly inundated areas of the floodplain along the Northwest Fork of the Loxahatchee River. During the 2000 field observations, it was noted that those cabbage palms still surviving in inundated areas did not appear as healthy as those did at higher elevations.

Table 33 (see also **Table B-3** and **Figure B-3** in **Appendix B)** shows that in 1940, there were about 163 acres of mangroves and 467 acres of cypress and stream swamp within the floodplain. Of the total 720 acres of floodplain vegetation identified in the 1940 aerial photography, 65% was represented by the stream swamp and cypress community while mangroves represented about 23%. Disturbed or cleared land represented 27 acres or about 4% of this coverage. Mangroves dominated the floodplain between river miles 4.5 and 6.0 and were present up to river mile 7.8. stream swamp and cypress were present upstream from about river mile 6.5 and were dominant above river mile 8.0.

1985 and 1995 Vegetation Communities

Beyond the obvious publicly owned lands and agricultural fields, the eastern portions of the Loxahatchee River Watershed were highly urbanized in the 1985 and the 1995 photographs (**Figure B-2, Appendix B**). A 1999 census estimate showed the Town of Jupiter with a reported population of 33,925 residents within the city limits. Jupiter residents plus neighboring municipalities accounted for a population of 77,484 residents (**Table B-1, Appendix B**). This number, however; does not include the residents of unincorporated Palm Beach County in the western portion of the watershed (e.g. Jupiter Farms). According to the Palm Beach County Planning and Zoning Department records, the 1999 census estimated an additional 10,506 residents in Jupiter Farms and 3,536 in Palm Beach Country Estates. Interstate 95 and the Florida

Turnpike stand out as major features that bisect the landscape along with extensive areas of agriculture (primarily citrus and cattle grazing), and the 11,471 acres of Jonathan Dickinson State Park.

Whereas in the 1940 black and white photographs the canopy appeared to be very uniform among swamp hardwood areas, in the 1995 photographs, the canopy seemed to have varying heights, colors and textures. Field observations showed that while some remaining areas maintained more than 50% cypress coverage, other freshwater communities consisted of mixed hardwoods including red maple (*Acer rubrum*), water hickory (*Carya aquatica*), laurel oak (*Quercus laurifolia*), pond apple (*Annona glabra*), pop ash (*Fraxinus caroliniana*), dahoon holly (*Ilex cassine*), and bay (*Persea* spp.) that are characteristic of a freshwater hardwood swamp. These areas were designated as “stream swamp” in the 1985 and 1995 coverages.

The most striking features noted in the comparison between the 1940 photos and those taken in 1985 and 1995 were as follows: a) the dredging and filling of former mangrove islands between river miles 4.5 and 5.5; b) the loss of floodplain and wetlands due to apparent flow diversions, invasion of upland species and development; and c) the effects of the placement of bulkheads along both shorelines of the estuary and lower Northwest Fork. Also, the islands and oxbows appear to have been heavily scoured over the years. These changes are reflected in total acreage differences between the 1940, 1985 and 1995 coverages. There is an overall loss of approximately 112 acres (17%) of wetland/floodplain area during this 55-year period (**Table 35**).

Figures B-2 and B-4, (Appendix B) illustrate the 1985 and 1995 distributions of vegetation within the floodplain. Color infrared photography allowed for the identification of a greater number of plant categories and better observation of vegetative changes. The 1985 photo represents the distribution of vegetation at the time that the Loxahatchee was designated as Florida’s first Wild and Scenic River. Whereas in 1940, mangroves were dominant between river miles 4.5 and 6.5 and were present up to RM 7.8, mangroves became dominant between river miles 5.5 and 8.7 and extended upstream to RM 10.4 by 1985. The floodplain in 1985 included 163 acres of mangroves, which represented 25% of the vegetation coverage in the Northwest Fork, and 390 acres of freshwater vegetation, representing approximately 61% of the coverage. Therefore, between 1940 and 1985, there was about a 10% loss of freshwater vegetation and a 4% increase in mangroves within the floodplain area. One would suspect that mangrove encroachment should be higher; however, between 1940 and 1985, there was a loss of mangroves reflected in the category Disturbed and Cleared Land, which increased from 4% in 1940 to 13% in 1985. Also, the floodplain decreased in acreage from 720 acres to 635 acres.

There were no major changes in coverage between 1985 and 1995. This relative stability of plant communities may be attributed to two factors. First, in 1987 additional culverts and operational criteria were added to G-92 to reconnect the Loxahatchee Slough with the NW Fork resulting in more water being added to the NW Fork (see section on *Hydrologic and Salinity Conditions* at the beginning of **Chapter 5**). Second, there was above normal rainfall and flow to the river during the 1990s. As a result of these changes, on average, an increase of 30 cfs has been delivered through G-92 and may have helped to stabilize the distribution of fresh and saltwater communities.

Both the 1985 and 1995 photographs show apparent changes in the distribution of mangroves and freshwater plant community coverages in the Hobe Grove Ditch and Cypress Creek areas (**Appendix B**). In 1985 and 1995, mangroves were present within the lower portion of Kitching Creek. Near the mouth of the creek, mangroves appear as forests whereas further upstream they appear as understory vegetation with a cypress/cabbage palm canopy areas dominated by cypress appear to be more closely associated with wider floodplains.

By 1995, there were 152 acres of mangroves (25%) and 371 acres of freshwater vegetation (60%) (see **Table 33;** also see **Table B-4** and **Table B-5** in **Appendix B)** along the Northwest Fork (east of Interstate 95 and the Turnpike). Although the total coverage of freshwater vegetation decreased by 144 acres (27%) between 1940 and 1985, only 19 additional acres were lost from this community between 1985 and 1995.

Figures 27 and **28** and **Figure B-7 (Appendix B**) illustrate the changes in freshwater and saltwater communities and disturbed lands between 1940 and 1995 by river segment. Most of the changes were observed within the Lower and Middle Northwest Fork segments. Between 1940 and 1995, mangroves exhibited both losses and gains (**Table B-10** and **Figures 27 and 28**) so that the total coverage remained essentially unchanged. Mangroves were lost due to development of islands between river miles 4.5 and 5.5 in the lower segment of the river, including 84 acres in the vicinity of Island Way Bridge. Mangroves increased in coverage upstream, primarily between river miles 6.0 and 8.5 in the middle segment, by invasion intofreshwater communities.

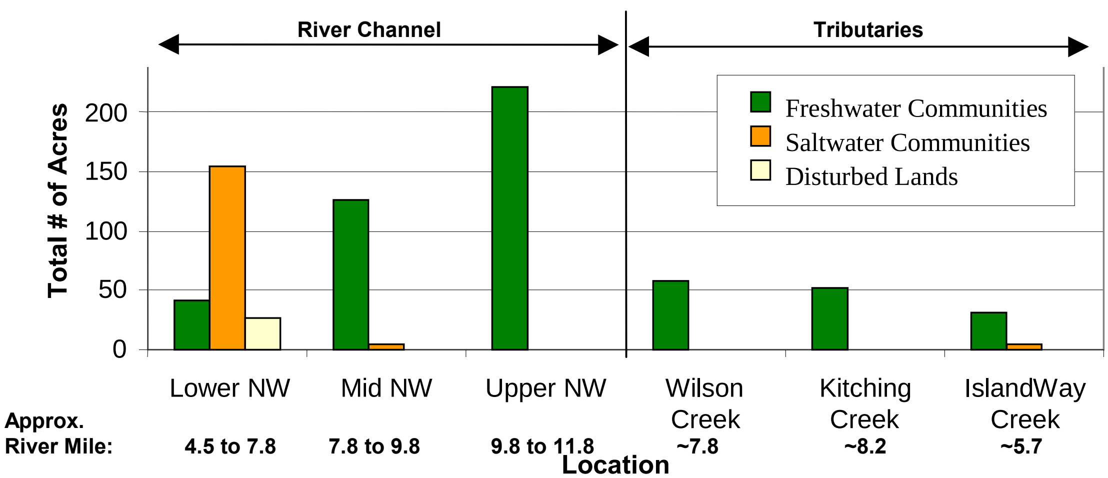


Figure 27. 1940 Vegetation Coverage along the Loxahatchee River, by Segment

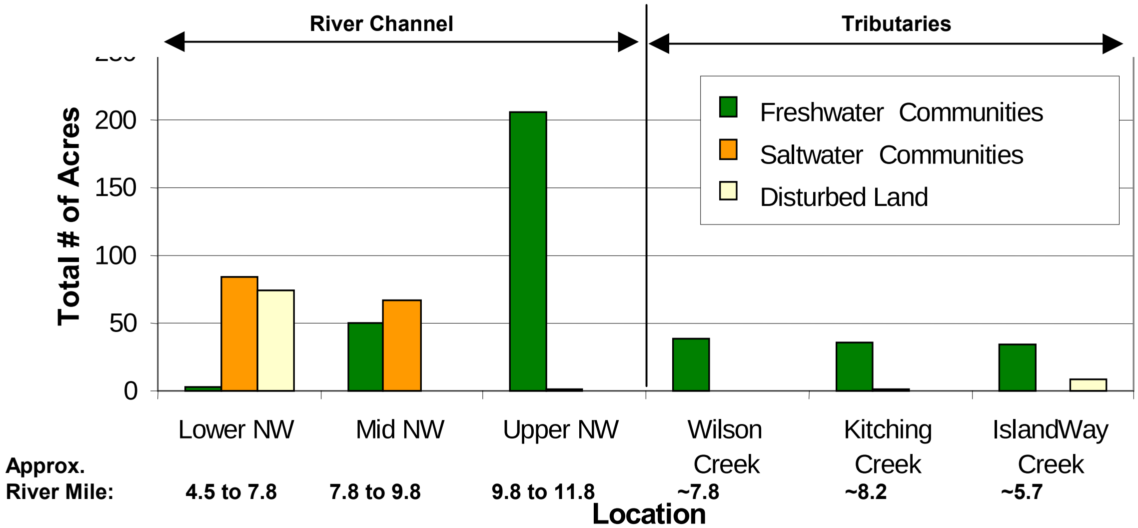
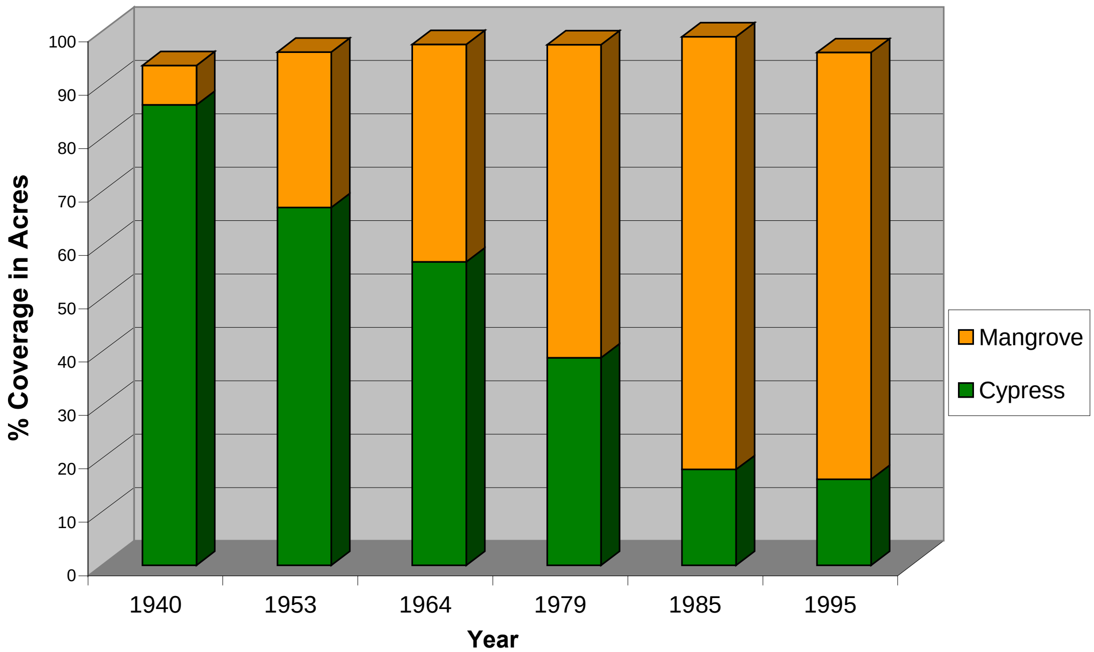


Figure 28. 1995 Vegetation Coverage along the Loxahatchee River, by Segment.

Freshwater communities were present in all segments, but primarily in the Upper NW segment. Disturbed and/or Cleared Lands were present primarily in the Lower NW segment. Those Disturbed Lands that were not developed reverted to mangrove communities. Brackish water marsh plants were observed as understory within these communities. As a side note, family photographs taken of plant communities in 1964 and 1966 (personal communication, Richard Roberts, Jonathan Dickinson State Park) provided clear evidence that large areas in the vicinity of the power lines (approximately river mile 6.5) that were brackish water marshes in 1964-66 were taken over by mangroves by 1985.

Six Decade Analysis

In order to provide a more detailed analysis of observed vegetation changes over time, District staff analyzed black and white aerial photographs taken of the Northwest Fork and floodplain, between river miles 6.6 and 8.9, during the years 1940, 1953, 1964 and 1979. These early vegetation coverages were also compared to more recent infrared Digital Ortho Quad photographs that were taken from the watershed during 1979, 1985 and 1995. Results of the six-decade analysis of vegetative changes are summarized in **Figures 29** and **30**. River miles 6.6 to 8.9 represent that area of the river where the majority of the vegetation changes have occurred during the past 55 years. Details concerning the methods that were used to interpret these photos are provided in **Appendix B** of this report. These figures clearly represent the progressive encroachment of mangroves and displacement of freshwater swamp communities that occurred between river miles 6.6 and 8.9.



.Figure 29. Mangrove Encroachment between River Miles 6.6 and 8.9.

1953 to 1979 Vegetation Coverages

Details of the 1940, 1985 and 1995 aerial photos were discussed earlier. Aerial photos from 1953 to 1979 were obtained, but were studied in less detail due to limited time and resources (see maps in **Figure 29**). Several overall trends and changes were nevertheless identified from this brief examination In 1953, mangrove coverage increases substantially in comparison to the 1940 photography. Mangroves represented about 29% of the total area, but still appear to be absent upstream of river mile 7.8. The coverage of the stream swamp and cypress community has decreased although it is still the largest (67%) category of coverage in the floodplain.

By 1964, the aerial photography shows additional replacement of the freshwater communities by mangroves. Mangroves had colonized the Northwest Fork as far as river mile 8.7 and were present at the mouth of Kitching Creek.

The 1979 photograph shows the continued decline of the freshwater communities and increase in mangrove coverage. Freshwater communities represented only 38% of the coverage. Mangroves had increased to 60% and had advanced to areas above river mile 9, which are located outside (upstream) of the regions shown in **Figure 30**.

Factors that Influenced Changes in Vegetation

Several field trips to the Loxahatchee River were made during 2000 and 2001 to gain general familiarity with the terrain and to groundtruth plant community signatures. During these trips it was noted that many of the remaining freshwater marsh areas, and Wilson and Moonshine Creeks have been heavily invaded by the exotic Old-World climbing fern, *Lygodium*.

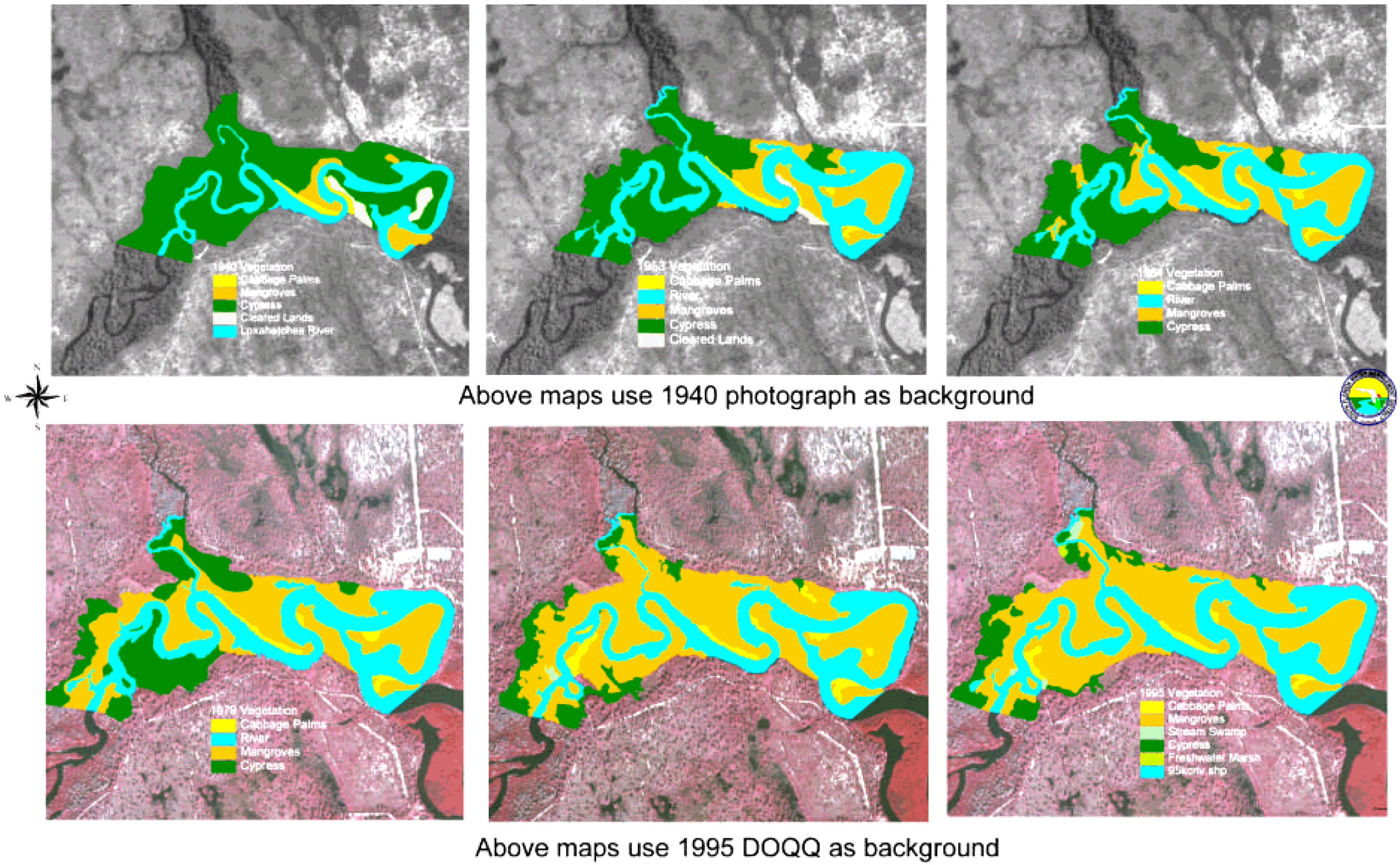


Figure 30. Vegetation Changes Along the Loxahatchee River between River Miles 6.6 and 8.9, 1940 to 1995

microphyllum. The *Lygodium* appears to smother existing vegetation. Also, there was apparently a net loss of brackish water marsh habitat, primarily between river miles 6.5 and 7.8 (**Appendix B**) associated with an invasion by mangroves during the 1990s.

The presence of mangroves along the lower NW Fork of the river shown in the 1940 photograph may be the result of several factors. Prior to 1947, the inlet opened and closed periodically. During periods when the inlet was open, saltwater may have had the opportunity to penetrate the lower portion of the river allowing mangroves to become established. Other factors that may have contributed to increased salinity levels within the estuary and lower Northwest Fork prior to 1940 include: (a) construction of the Intracoastal Waterway in 1928 that linked the St. Lucie inlet with the Lake Worth inlet, (b) USACE dredging of the inlet and lower estuary; (c) construction of the Lainhart and Masten dams; (d) construction of Bridge Road, which reduced inflow from Kitching Creek; and (e) construction of a small agricultural ditch that diverted water from the Loxahatchee Slough marsh to the SW Fork of the river.

Several additional changes had occurred by 1953. These major changes river vegetation correspond to the opening of the Jupiter Inlet in 1947 which permanently changed the lower estuary from a freshwater/brackish water system to a salinity regime more characteristic of estuarine conditions (USACE 1966). In addition, back-to-back hurricanes of the late 1940's and their associated high winds and storm surges may have transported mangroves propagules far up river, accounting for some of the mangrove colonization shown in the 1953 photography.

Vegetation changes observed after 1953 are probably related to physical and hydrological changes that occurred in the late 1950's. Between 1957 and 1958, the USACE constructed the C-18 Canal, channelized the Southwest Fork, and constructed the S-46 structure for flood control purposes. These flood control improvements however diverted water away from the Northwest Fork to the Southwest Fork (McPherson et al. 1982). High (spring or wind-driven) tide events, occurring during periods when river flow was reduced, could have transported mangrove propagules upstream. In addition, during the 1960's a developer also dredged and filled a number of mangrove islands within lower portion of the river and cut a channel through the sandbar ("S-bar") that historically provided a natural saltwater barrier to the upper reaches of the river. As a result of these projects, saltwater could now more freely penetrate the Northwest Fork of the river during low flow and high tide periods.

Observed vegetation changes that occurred by 1979 correspond with the continued operation of the C-18 canal which essentially eliminated freshwater flow from the Loxahatchee Slough to the Northwest Fork from the time the C-18 canal project became operational (early 1960's) until the construction of the G-92 structure in 1974. In addition, dredging of the central embayment area (McPherson et al. 1982), combined with oyster bar removal projects (Chiu 1975), and replacement the Alternate A1A bridge over the Loxahatchee River are thought to have improved tidal flushing of the estuary. These projects may have also played a role in allowing saltwater and mangrove propagules to further penetrate the lower portion of the river during dry periods. Review of long-term rainfall records also show that during the 1970's, the region experienced a number of back-to-back below normal rainfall years which also contributed to the river's saltwater intrusion problems .

The apparent lack of change in distribution of plant communities between 1985 and 1995 (**Figure 29)** can be attributed to increased flows delivered through G-92 and an increase in rainfall during the 1990s. In 1987, additional culverts were placed in G-92 to allow larger discharges and automated equipment was installed to remotely operate the G-92 Structure. Operational criteria were also added to G-92 to reconnect the Loxahatchee Slough with the NW Fork, resulting in more water being added to the Northwest Fork. Other visible hydrologic or structural changes noted in the 1995 photographs included the following:

- Over 3,000 acres of citrus groves have been planted west of the NW Fork
- Hobe Grove Ditch was dug through uplands to provide flood control for citrus groves during the 1960s. Surface water flowing from this area during dry periods is now being retained to maintain the water table for these irrigation wells.
- Most of the remaining inland ponds and sloughs appear to be much smaller in size in comparison to the 1940 photographs.

Comparison to Previous Studies

The 1973 field observations of Alexander and Crook (1975) provided a record of the floodplain vegetation in several locations along the Northwest Fork and Kitching Creek. In Alexander and Crook's (1975) study, Site 10 was located on Kitching Creek; Sites 13, 14, and 15 were located on the NW Fork (**Figure B-6, Appendix B**).

Comparison of the SFWMD interpretation of 1940 photography with vegetation described by Alexander and Crook (1975) vegetation from historical aerials revealed similar results. Alexander and Crook (1975) interpreted Site 10 as a swamp hardwood community that was dominated by water oak, maple, ash, and pond apple. Sites 13 and 14 were interpreted as mangrove communities, while Site 15 was interpreted as a cypress canopy with a mangrove understory. In our interpretation of these same areas (**Figure B-8, Appendix B**), Sites 10 and 15 were still swamp hardwoods, while Site 13 was predominately swamp hardwood with a small amount of mangrove at the southern tip. Site 14 was interpreted as predominately mangrove with some cleared land. For their 1973 field observations to groundtruth 1970 black and white aerials, Alexander and Crook determined that sites 14, 15, and most of Site 13 were mangrove communities. Within Site 10, swamp hardwoods were still present just outside of the mouth of Kitching Creek. Field surveys of these same areas were groundtruthed by District staff in November 2000. The following changes in river vegetation were observed:

- Site 10 – (Kitching Creek) mangroves are present up to the second bend in the creek and occur further upstream as understory. Freshwater communities were a mixture of cypress, stream swamp, and freshwater marsh. The largest freshwater marsh area is dominated by small pond apple trees with an understory of sawgrass and ferns. This area also appeared to have been previously logged.
- Site 13 - This site is almost completely mangrove. A small remnant of the live cypress remains on the northern boundary adjacent to the uplands probably due to its distance from the riverbed and influence of the adjacent ground water.

- Site 14 - a large red mangrove island with leather fern and string lily (*Crinum americanum)* understory, has not changed except the tree heights no longer reach 30 feet
- Site 15 - predominately mangrove with the only live cypress remaining along a north-eastern ridge and some concentrated areas of cabbage palms found on another ridge area.

Results of this study were also compared to observations by Duever and McCollum (1982). These authors analyzed cypress tree rings at 11 sites along the Northwest Fork and determined that encroachment of mangroves coincided with increases in small and poor quality rings. At sites downstream of river mile 9, Duever and McCollum (1982) observed that small and poor quality rings increased from 22% in 1950 to 58% and 79% by the late 1970s. At sites upstream of RM 9, the percent of large "healthy" rings increased since 1940, with the exception of a decline in ring size that occurred during the late 1950s. These observations probably relate to permanent opening of Jupiter inlet In 1947 and construction of C-18 canal in 1957-58.

Results of this study show that over the past 55 years, mangroves have gradually replaced saline and freshwater marsh communities, cypress and stream swamp habitats on the Loxahatchee River. Although mangroves have replaced a considerable amount of the downstream historical coverage of freshwater vegetation along the Northwest Fork of the Loxahatchee River, the Wild and Scenic River segments of the waterway continue to be a valuable natural resource and tourist attraction. Both mangrove and cypress communities provide important habitats for wildlife that utilize this river.

Summary

Results of the comparisons of aerial photographs from 1940, 1985, 1995 and other years showed the following:

- An apparent reduction in total acreage of the river floodplain between 1940 and 1995 can be attributed to several causes, including scouring of the riverbed, bulkheading, development, and loss of wetland vegetation to transitional and upland species due to flow diversion and lowering of water levels in the watershed. Most of the vegetative changes occurred in the lower and middle segments of the Northwest Fork and were documented by more detailed examination of the area between river miles 6.6 and 8.9
- 1940 aerial photography of the watershed revealed an abundance of swamps, wet prairies, inland ponds, and sloughs. Mangroves were present from river mile 4.5 to river mile 6.0 and extended upstream to river mile 7.8. Freshwater stream swamp and cypress communities were present upstream from river mile 6.5 and were dominant within the floodplain portion of the study area above river mile 8.0, comprising about 73% of the vegetative coverage of the Northwest Fork, while mangroves represented 22%.
- By 1985, much of the watershed had been developed with the exception of Jonathan Dickinson State Park. Freshwater communities represented 61% of the total coverage. Mangroves represented 25% of the coverage and may have extended upstream above river mile 10. Mangroves experienced only a 4% increase in overall coverage due to losses of these plants from islands in the floodplain that were urbanized. Freshwater communities decreased by 10%.

- Freshwater flows to the Northwest Fork increased during the period between 1985 and 1995, due to construction and improved operation of the G-92 Structure and increased rainfall. These changes may account for the fact that only minor differences in vegetative coverage occurred during this ten year period.
- Improved aerial photography that was used during 1985 and 1995 made it possible to distinguish differences in structure and composition of the freshwater communities. This improved resolution may account for the apparent increase in number of species and apparent loss of cypress dominance along the immediate river corridor upstream of river mile 9. Such changes could also be explained by the impact of saltwater intrusion and decreased surface and ground water inflow.
- An analysis of six decades of change based on aerial photographs and review of other research studies, indicates that most of the mangrove encroachment seemed to occur between 1953 and 1979. This timeframe also correlates to the period when small and poor quality rings were formed in cypress trees in the River floodplain (Duever and McCollum 1982). Also during this period, the inlet was stabilized and freshwater flow was redirected from the Northwest Fork to the Southwest Fork of the river for flood control.
- The results of Alexander and Crooks' (1975) investigations of several sites along the NW Fork and Kitching Creek were similar to the vegetation patterns derived from 1940 aerial photography. More recent photographs and limited field observations indicate that a steady increase in the invasion of mangroves has occurred in the segment of the river between river miles 4.5 and 8.9 since their 1973 field inspections.

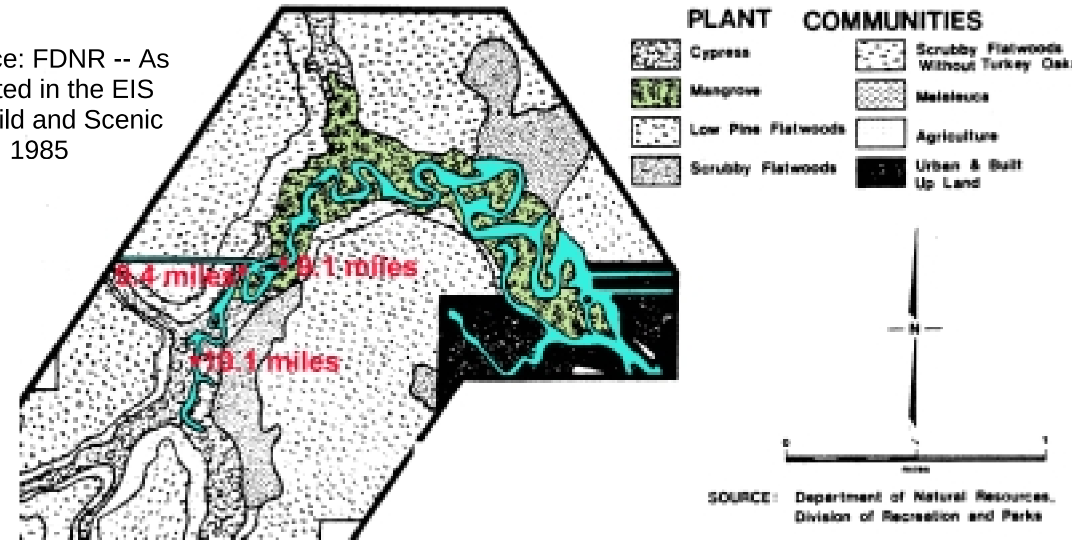
Vegetation Changes along the Northwest Fork Since 1985

A baseline or reference point must be identified as a basis to establish an MFL. The SFWMD staff selected the condition of the river at the time that Northwest Fork was designated as a "Wild and Scenic River," in 1985. This point was chosen because the river management Plan (SFWMD, 2002) recognized the values of the river at that time and identified the need to protect and enhance these resources. In addition, several types of information are available to provide a description of the condition of the resource at that time

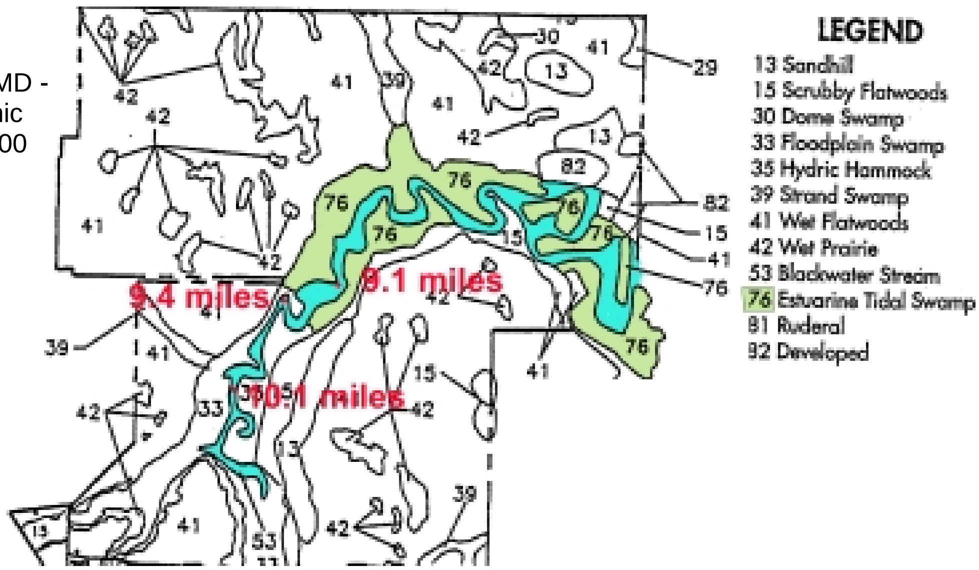
A review of reports and documentation of vegetation communities along the Northwest Fork was conducted in order to determine the extent of vegetation communities when the River was federally designated as "Wild & Scenic". This information is also useful to determine if the vegetation is still changing when compared with the current (2002) vegetation surveys (see **Figure 29, Figure 30 and Table 33**). Reports that were reviewed include the Final Wild and Scenic River Study Environmental Impact Statement (EIS)(United States Department of the Interior/National Park Service, 1984) and the Loxahatchee River National Wild and Scenic River Management Plan (SFWMD, 2002).

The EIS provides a map of river vegetation (**Figure 31-A**) and generally describes the vegetation of the river from its source upstream of Indiantown Rd. to the mouth of the Jupiter Inlet. Vegetation was described as a canopied cypress river-swamp community from Indiantown

A.
Source: FDNR -- As reported in the EIS for Wild and Scenic River 1985



B.
Source: SFWMD - Wild and Scenic River Plan, 2000



C.
Source: SFWMD -- Results of 2001-2002 river surveys

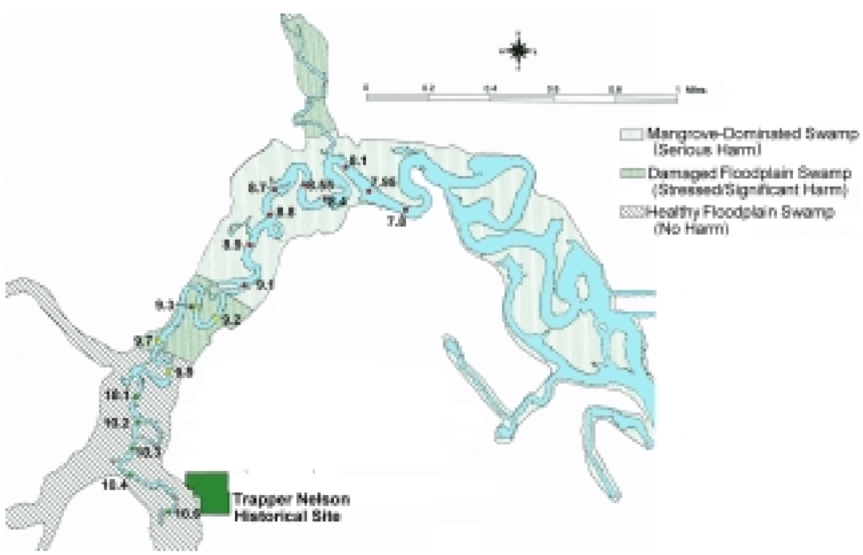


Figure 31.Maps showing results of vegetation surveys along the Northwest Fork, 1985 - 2000

Rd. to the Trapper Nelson Interpretive Site. Downstream of Trapper Nelson's the vegetation changes and is described as mangrove-dominated swamp with dead cypress trees at river mile 9.0 (revised river mile 9.4). At river mile 9.5 (revised river mile 10.1), the first mangroves are found and most cypress trees appear to be stressed. Current vegetation studies indicate that the area of stressed freshwater swamp hardwoods and cypress begins further downstream, near (revised) river mile 9.7.

It is not known why there is a discrepancy between the location of the "stressed" area from 1984 (revised river mile 10.1) to 2002 (revised river mile 9.7, **Figure 31-C**), however a couple of explanations are plausible. It may be possible that increased rainfall and flows to the Northwest Fork during the 1990's have led to the recovery of the swamp forest in the area around revised river mile 10.1. Or, perhaps the measurement of river mile locations was not as precise when calculated in 1984 and the location was intended to be an approximation only.

The River Management Plan (SFWMD 2002) provides a description and map of dominant vegetation along the NW Fork (**Figure 31-B**). This document indicates that the cypress community

> "solidly flanks the river and its tributaries upstream from about river mile 9.5 (revised river mile 10.1), and is the dominant species to above river mile 9 (revised river mile 9.4). The mangrove community solidly lines the river downstream from river mile 9 (revised river mile 9.4) . . . dead cypress trees tower above the red mangroves for one or two miles downstream from this point, evidence of the extent of freshwater vegetation that existed before changes in the upstream movement of salt water."

This observation is in line with vegetation data collected along the Northwes Fork in studies from 2000-2002 (**Table 32** and **Figure 31-C**), which indicates that the vegetation zones classified as "healthy", "stressed", and "mangrove swamp" closely correspond to these same locations in 2002. Based on this comparison of vegetation community descriptions from 1985 and 2002, it can be inferred that there has been little change in the distribution of freshwater and salt-tolerant vegetation since the mid-1980's.

Other Factors Considered

The vegetation survey data collected along the Northwest Fork of the Loxahatchee River documents that a gradient of change occurs, from a freshwater-dominated floodplain swamp to a saltwater-tolerant red mangrove community. These observed changes appear to be highly correlated with distance from the Jupiter inlet and the salinity gradient that exists along the Northwest Fork. We also considered other factors that may explain the current distribution of river vegetation species found along the Northwest Fork. These include possible changes in fire frequency, excessive flooding, and the effects of drought. A review of the literature relative to bald cypress and aerial photography/GIS studies of long-term vegetation changes in the basin as presented in this report indicates that none of these factors can account for the overall pattern of vegetation change observed during the past half-century.

Fire frequency in the river floodplain is generally low, primarily because the soils are saturated most of the year, which retards the spread of fire. Furthermore, dry fuel in the floodplain swamp is sparse, and rapid decomposition rates and frequent flood events tend to clear away fuel. Bald cypress and mixed hardwood forests thrive in both fire free habitats and in occasionally burned areas (see Gunderson 1984, Ewel 1990a). Bald cypress have been found to recolonize after fire, if a local seed source is available (Gunderson 1984).

Excessive or prolonged flooding of the floodplain along the Northwest Fork is unlikely, especially since historic water tables have been reduced and hydroperiods shortened over the past century (see Aerial Photography/GIS studies, **Appendix B**). In spite of this, flooding may be more frequent along downstream segments where tidal action is a dominant hydrological force. However, bald cypress have been found to grow naturally in flooded swamps and lakes 90-100 m from the shoreline, some in water 1-3 m or more deep and at time of floods, the depth may be greater for short intervals (Brown 1984, Lugo and Brown 1984). Conversely, bald cypress are successfully grown in moist soils as well as in much drier landscape situations where flooding never or rarely occurs. Drought would induce short-term restrictions on growth of bald cypress, but would not explain the pattern of loss we have observed along the River. If either of these factors (prolonged flood or drought) had a major influence on the loss of bald cypress and mixed hardwoods along the Northwest Fork, it would be expected to cause widespread loss across the floodplain, rather than only along a front that is closely associated with distance from the inlet.

PROPOSED VEC FOR THE NORTHWEST FORK

Rationale for VEC Selection

The SFWMD Coastal Ecosystem Department's research program supports application of a resource-based management strategy defined as the "Valued Ecosystem Component" (VEC) approach. This evaluation methodology is similar to a program developed as part of the National Estuary Program (USEPA 1987). For the purposes of this study, the VEC approach is based on the concept that management goals for the Northwest Fork of the Loxahatchee River can best be achieved by providing suitable environmental conditions that will support certain key species, or key groups of species, that inhabit the system. In most instances the VEC represents those species that are most sensitive to the environmental factor of interest. Protection of these species assumes protection of the entire community. A VEC can be defined as a species, community or set of environmental conditions and associated biological communities that are considered to be critical for maintaining the ecological sustainability of the Northwest Fork's floodplain swamp community.

Based on the results of a vegetation survey of the Northwest Fork of the river (presented previously in this chapter), District staff propose that a group of six key woody vegetation species that characterize the upstream floodplain swamp forest should represent the VEC for the purpose of establishing a MFL for the Northwest Fork of the Loxahatchee River. Impacts to the VEC below a critical level are considered to constitute significant harm to the floodplain swamp community. The VEC approach was applied to the Northwest Fork of the Loxahatchee River based on the following relationships:

- Results of two river vegetation surveys showed that the bald cypress community is not a sensitive indicator of salinity stress within the Northwest Fork of the Loxahatchee River.
- These results showed that six “key” woody vegetation species, which are characteristic of the floodplain swamp, appear to be more responsive to long-term changes in river salinity than cypress, cabbage palm or red mangrove communities, and therefore qualify as a more sensitive VEC for the Northwest Fork of the Loxahatchee River.
- These six species (red maple, pop ash, red bay, Virginia willow, Dahoon holly, and pond apple) have physiological characteristics that play important functional roles in the forest ecology. These characteristics also make them useful indicators of long-term salinity conditions.
- Based on these relationships, District staff chose the six species listed in **Table 29** as the selected VEC for the Northwest Fork of the Loxahatchee River.

Species Selected

“Key” species as defined in this study refer to those selected from the results of the river survey and a corresponding literature review (**Table 29**) of vegetation salinity tolerances. The criteria for selection of these key species were as follows:

- Species that play important roles in freshwater swamp ecology by providing food, substrate or habitat for other species and thus are useful indicators of long-term ecosystem health.
- Species that are widely distributed within the floodplain corridor and in South Florida freshwater swamps (i.e. not found only in localized populations). This criterion is used to ensure that observed trends are most likely not due to natural variability that could account for uneven distributions.
- Species that are significant components of the local riverine swamp community in terms of density and physical forest structure. This criterion was intended to exclude minor (rare) species and to select those that were primary constituents of forest structure, and whose overall abundance can be reliably measured by reasonable sample sizes.
- Terrestrial species that are rooted in the soil substrate (i.e. not floating or epiphytic). This excludes aquatics, which may reflect only short-term (transient) salinity conditions.
- Species that are relatively long lived (more than 10 years, i.e. generally woody or tree species), which are more reliable indicators of long-term conditions. Herbaceous species were excluded, as they typically have shorter life spans (less than 10 years).
- Species that occupy different ecological niches and have different functional roles in the freshwater swamp (i.e. canopy, sub-canopy, shrubby). A decline in one or more of these functional roles can have ecological consequences, such as impacts to wildlife.
- Species that are copious producers of differing seed types (e.g. berries, samaras, etc.) that are readily spread (e.g. air-borne, water-borne, bird-dispersed) throughout the area. This

helps to ensure that an observed decline in seedling or sapling numbers is not related to localized seed production or species-specific dispersal characteristics.

- Species that represent a range of saltwater tolerance and sensitivities (i.e. obligate freshwater species, saltwater tolerant species, and transitional species). This characteristic will help to document the range of salinities and changes along the Northwest Fork.

Information gathered from the vegetation survey indicated that a group of nine species would fit the criteria described above. These species are listed in **Table 28** along with their relative salinity tolerances obtained from a review of the available literature.

Summary

- Overall, the vegetation survey data collected along the Northwest Fork of the Loxahatchee River shows that a gradient of change exists, from a freshwater-dominated floodplain swamp to a saltwater-tolerant red mangrove swamp.
- Results of quantitative and semi-quantitative surveys showed declines in number of VEC species, number of individuals, canopy area, tree height, tree trunk diameter, and the number of seedlings and saplings present at river vegetation sampling sites located closer to the Jupiter inlet, which is the source of salinity for the Northwest Fork.
- Quantitative survey results also showed that locations at and above river mile 10.2 have a full canopy cover and contain reproducing populations of cypress and all six VEC species that are characteristic of the floodplain swamp community. From these data, District staff concluded that this area of the river currently represents an unharmed, healthy, sustainable floodplain swamp community.
- Results of semi-quantitative survey indicate that a healthy floodplain swamp community probably continues to exist downstream to river mile 9.8
- At river mile 9.7, although all six VEC species were present, there were observed reductions in canopy cover, a decline in the mean height and trunk diameter of VEC tree species, and a reduction in the number of seedlings and saplings present. These results suggest that several functional characteristics of the floodplain swamp at this location in the river have been, or currently are, stressed by periodic exposure to low salinity levels.
- The most significant result of this study shows that downstream of river mile 9.1 all six VEC species were eliminated from the floodplain and replaced by saltwater-tolerant mangroves. A short distance upstream at river mile 9.2, no VEC saplings or seedlings were present and only three out of the six VEC species remained as part of the floodplain swamp forest. In addition, the high canopy has been virtually eliminated and replaced by a low canopy dominated by red mangroves at river mile 9.2.
- These observed changes in species composition, forest structure, and reproduction capabilities strongly indicate that a major change has occurred to the floodplain swamp forest community that can affect the microclimate, ecological function, and species composition of both flora and fauna within the Northwest Fork. For these reasons, river mile 9.2 was selected as the baseline location in the river where significant harm occurs.

APPLICATION OF MODELING TOOLS

Analysis of the Simulated Long-term Salinity Record

Since long-term salinity records do not exist for each vegetation sampling site it was necessary to develop a method for estimating or "hindcasting" a 30-year salinity time series for the river. This was accomplished through the use of a hydrodynamic model developed for the Loxahatchee River and estuary. Development, application and calibration of the hydrodynamic/salinity model is provided in **Chapter 4 – Methods** and in **Appendix E** of this document. Results of the simulated 30-year time series, for each vegetation monitoring site, are shown in **Tables H-2** through **H-4** in **Appendix H**. Sample outputs of these data are shown in **Figure 32** for stations at river miles 10.2 and 9.2 respectively. From these time series basic statistical measures (mean, standard deviation, median, mode, 90th percentile distribution limits, and maximum daily salinity concentrations) were determined for each vegetation sampling site **.**

The simulated salinity data were also analyzed in terms that are more relevant to the biology of the floodplain swamp community, i.e., the degree of exposure to low salinity conditions in terms of magnitude, event duration and time between events. It was assumed that some "threshold" level of salinity concentration, duration and return frequency exists that, when exceeded, causes an impact to a plant community. For example, along upstream segments of the Northwest Fork, a salinity event may occur at or above a specific threshold level for a number of days at a particular site. This event is followed by a period of time where freshwater conditions return and recovery from the salinity event occurs. To capture this salinity event-recovery cycle and the net effect it may have on the freshwater plant community, the long-term salinity data were examined in terms of salinity event duration (*Ds*) and elapsed time between events (*Db*) for a particular threshold.

Exposure to Different Salinity Concentrations at Particular Locations

Statistical Properties of Predicted Salinity Concentration Data.

The summary statistics for each station (**Table 34**) indicate the salinity average, variability and extreme conditions for each station during the 30-year simulation period. The 90th percentile limit shows the level of salinity exposure that might be expected to occur during extreme events. Within the unharmed, healthy floodplain swamp community (river mile 10.2), salinities ranged from 0-3 ppt with a mean of 0.15. The upper 90th percentile of the salinity distribution at mile 10.2 was 0.65 ppt (i.e. 90% of the time, the average daily salinities at this location are below 0.65 ppt). At the stressed station (river mile 9.7), salinities ranged from 0-6 ppt with a mean of 0.5 and an upper 90 percentile limit of 1.7 ppt. At the significantly harmed station (river mile 9.2), salinity ranged from 0-9 ppt with a mean of 0.97 and 90% limit of 2.9 ppt.

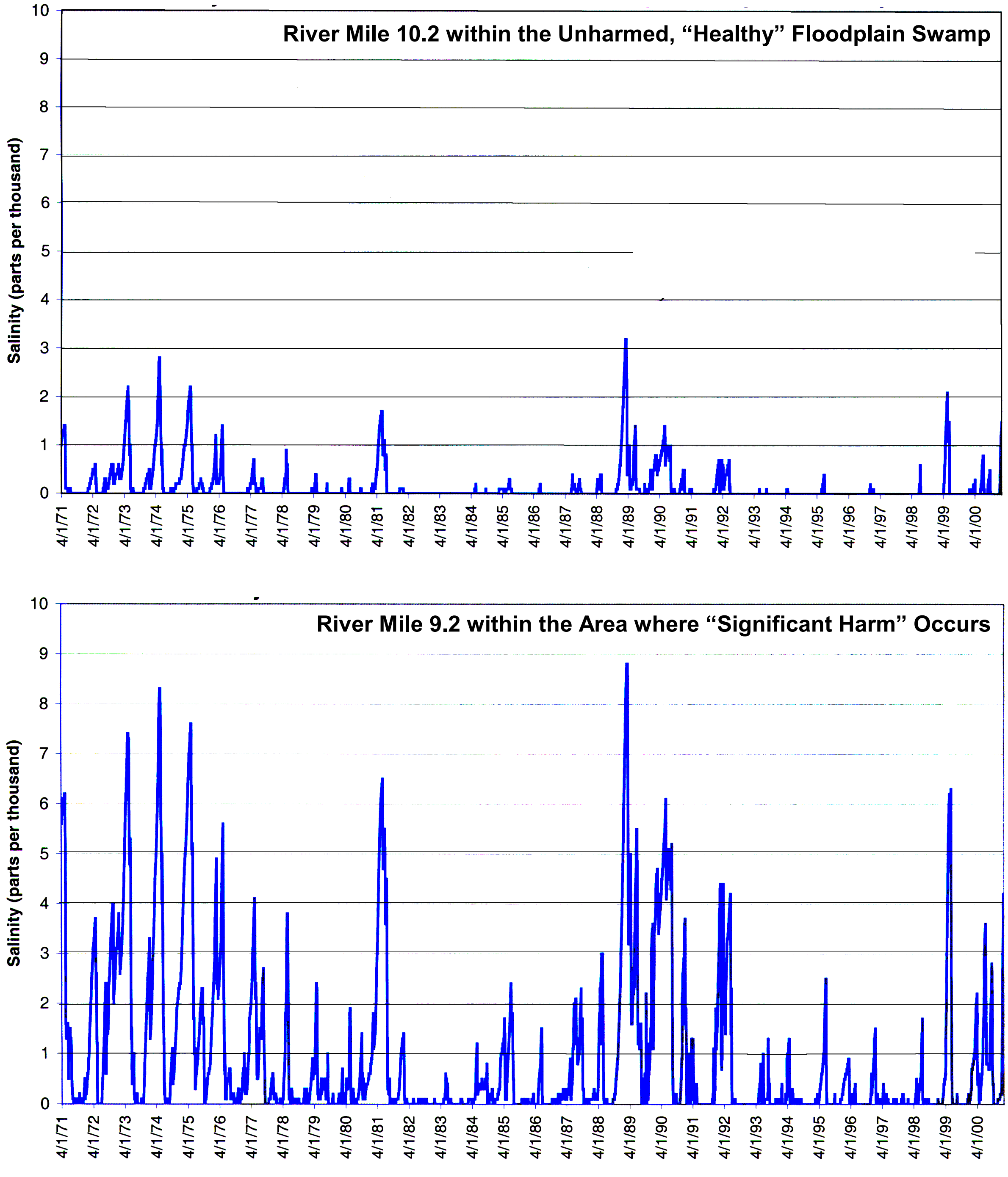


Figure 32. Simulated salinity time series generated from the hydrodynamic/salinity model developed for the Loxahatchee River showing the salinity regime (expressed as estimated mean daily salinity) at river miles 10.2 and 9.2, Northwest Fork of the Loxahatchee River

Table 34. Summary statistics of estimated mean daily salinity concentrations for the 30-Year simulation period (1971-2001) for seven river vegetation sampling sites.

Site Name	River Mile	Salinity (ppt)			
		Mean	Standard Dev. (SD)	Upper 90% limit (Mean +1.28●SD)	Maximum Predicted
7-C (WQ Sta. #64)	7.8	6.154	5.226	12.84	21
8-B	8.4	3.744	4.055	8.93	18
WQ Sta. #65	8.6	2.811	3.385	7.14	16
8-D	8.9	1.836	2.642	5.21	14
9-B	9.2	0.967	1.614	2.93	9
9-C	9.7	0.480	0.937	1.68	6
10-B	10.2	0.154	0.386	0.65	3

Table 35. Duration of exposure to estimated mean daily salinity concentrations from the 30-year model simulation for seven vegetation sampling sites located along the Northwest Fork

Site	River Mile	number of days (percent of time) exposure to salinity levels			
		0.5>1≤1.5 ppt	1.5>2≤2.5 ppt	2.5>3≤3.5 ppt	3.5>4≤4.5 ppt
7C (WQ #64)	7.8	9253 (84.9)	7914 (72.6)	6690 (61.4)	5831 (53.5)
8B	8.4	7038 (64.6)	5496 (50.4)	4613 (42.3)	3873 (35.5)
WQ #65	8.6	5870 (53.9)	4562 (41.9)	3666 (33.6)	3013 (27.6
8D	8.9	4525 (41.5)	3297 (30.3)	2497 (22.9)	1959 (18.0)
9B	9.2	3071 (28.2)	1953 (17.9)	1297 (11.9)	834 (7.7)
9C	9.7	1670 (17.2)	906 (8.3)	418 (3.8)	161 (1.5)
10B	10.2	568 (5.2)	113 (1.0)	14 (0.1)	0 (0.0)

Distribution of Salinity Concentrations.

To provide more information about the frequency and duration of salinity exposure for each plant community during the 30-year time period, the number of days and percent of time that various locations on the river were exposed to average salinities of 1 ppt, 2 ppt, 3 ppt etc. were calculated (**Table 35)**. Within the unharmed, floodplain swamp community (river mile 10.2), the estimated long-term salinity regime showed that plant communities at this site were exposed to mean daily salinities of 1 ppt during 568 days or 5.2% of the simulation period. Average salinities of 2 ppt occurred during 1.0% of the simulation period and salinities of 3 ppt occurred during 0.1% of the siumulation period. At the stressed station (river mile 9.7), salinities of 1 ppt occurred during 17%, 2 ppt during 8.3% and 3 ppt during 3.8% of the simulation period. At the significantly harmed location (river mile 9.2), salinities of 1 ppt occurred 28%, 2 ppt 18%, and 3 ppt occurred during 12% of of the simulation period (**Table 35**).

Duration and Frequency of Exposure.

Average exposures, however, do not give an adequate indication of the amount of stress that may be experienced by a biological community. The duration of a particular event must be considered as a well the amount of time that elapses between events (recovery period). The duration of exposure that a particular species can tolerate and the amount of time needed for recovery to occur are unknown for these species. General criteria, for application at the community level, have been inferred from the available data. **Table 36** shows the mean duration of salinity events (*Ds*) and the mean time between salinity events (*Db*) at or above the selected threshold values for the modeled period. For this analysis, the mean daily salinity level, as predicted by the model, was treated as a threshold rather than an average. For example, salinity at river mile 9.2 was plotted as a function of time, as shown in **Figure 32**. The number of events when mean daily salinity equalled or exceeded 2.0 ppt, the duration of each event and the elapsed time from one event to the next were determined.

Table 36. Salinity Event Duration (days) and Time Between Events (days), based on Simulated Salinity "Threshold" Levels, at Seven Sites along the Northwest Fork of the Loxahatchee River.

Site	River Mile	Mean Duration (*Ds*) of Exposure to Salinity Thresholds and Elapsed Time Between (*Db*) Salinity Events									
		Salinity ≧ 1ppt		Salinity ≧ 2ppt		Salinity ≧ 3ppt		Salinity ≧ 4ppt		Salinity ≧ 5ppt	
		Ds	*Db*	*Ds*	*Db*	*Ds*	*Db*	*Ds*	*Db*	*Ds*	*Db*
7C (WQ #64)	7.8	157	14	76	20	50	26	44	33	44	43
8B	8.4	83	23	49	39	52	62	48	77	45	94
WQ #65	8.6	67	30	68	70	58	85	56	111	40	124
8D	8.9	54	52	47	90	46	130	37	144	35	191
9B	9.2	55	143	46	207	45	344	41	504	29	612
9C	9.7	38	189	40	455	34	874	20	1800	22	5422
10B	10.2	31	576	22	2157	13	10899	0	10912	0	10912

Salinity-exposure events increase in magnitude, occur more frequently, and last longer as one moves downstream. At the unharmed station 10B (river mile 10.2), salinity intrusion events above 1 ppt concentration, of about 30 days duration, occur once every 576 days (1.6 years). Salinities above 2 ppt occur for 22 days every 2157 days (5.9 years). Salinities as high as 3 ppt occurred once during the period of record (10,899 days or about once every 30 years). At the stressed station (river mile 9.7), salinities exceeded 1 ppt for approximately five weeks, twice per year. Salinities above 2 ppt occurred for 40-day periods, less than once a year. Salinities exceeded 3 ppt for approximately one month every 2.4 years. At station 9B (river mile 9.2), where significant harm has been observed, salinities exceed 1 ppt approximately four months per year. Salinities above 2 ppt occurred for 46-day periods, about twice a year. Salinities exceeded 3 ppt for approximately 45 days every year (**Table 36**).

Effects of Flow from Lainhart Dam on Salinity Conditions in the River.

Based on the results of the hydrodynamic/salinity model a flow/salinity relationship was established for each of the seven vegetation sampling sites located along the Northwest Fork. **Table 37** provides output from the model showing the amount of river flow that is required to maintain average salinity conditions (mean daily concentration) at different points along the river.

Details of the methods and graphical results of these analyses are provided in **Appendix H.** For example at river mile 9.2, a flow of approximately 35 cfs from the Lainhart Dam is sufficient to maintain an average salinity of 1.9 ppt, whereas downstream at river mile 8.4, the amount of flow required to maintain the same average salinity is about 65 cfs.

Table 37. Flow required from the Lainhart Dam to maintain mean tide salinity levels at selected river miles.

Flow (cfs)	Mean Tide Salinity levels (ppt)							
	RM 10.2	RM 9.7	RM 9.4	RM 9.2	RM 8.9	RM 8.6	RM 8.4	RM 7.7
200	0.10*	0.10	0.10	0.10	0.11	0.12	0.13	0.21
150	0.10	0.10	0.11	0.11	0.12	0.15	0.19	0.39
100	0.10	0.11	0.12	0.14	0.20	0.34	0.47	1.462
85	0.10	0.12	0.14	0.18	0.29	0.54	0.87	2.29
65	0.11	0.17	0.2	0.34	0.66	1.26	1.92	4.16
55	0.1	0.3	0.4	0.6	1.1	2.0	2.8	5.5
50	0.14	0.30	0.5	0.80	1.32	2.32	3.28	6.18
45	0.2	0.4	0.7	1.1	1.8	2.9	4.0	7.1
40	0.19	0.57	0.9	1.40	2.20	3.53	4.72	8.04
35	0.3	0.9	1.3	1.9	2.9	4.4	5.7	9.2
30	0.34	1.15	1.8	2.48	3.58	5.29	6.70	10.36
20	0.78	2.34	3.3	4.24	5.64	7.70	9.27	13.12
10	2.01	4.67	5.9	7.17	8.81	11.16	12.78	16.59

* Values represent mean tide salinity levels, vertically averaged for the entire water column

Chapter Summary

- Long-term flow records for the Loxahatchee River indicate that average flows during the dry season (October 16-May 14) are 70 cfs. During extremely dry conditions, such as existed during the 1980-81 and 1989-90 droughts, dry season flows from Lainhart Dam averaged between 26-35 cfs (**Table 23**).
- Examination of the flow record for Lainhart Dam from 1977 to 2001, indicates that increased rainfall and improvements to the G-92 structure in 1987, have increased average flow to the river from 52 cfs to 86 cfs (**Figure 19**). Also the occurrence of flows below 35 cfs has been reduced from 34 percent of the time (1971-1989) to 25 percent of the time (1990-2001) (**Table 24**). These changes can be attributed to a combination of changes in weather patterns and improved management practices.
- Review of flow duration curves developed for the Lainhart Dam shows that about 10% of the time, flows are reduced to about 14 cfs over the 30 year period of record (**Figure 20**).
- Results of a river vegetation survey identified six species of woody vegetation species (red maple, pop ash, dahoon holly, pond apple, Virginia willow and red bay), which predominantly occur in fresh water (**Table 29**), as useful indicators of long-term salinity changes within the river. These six species were selected as the Valued Ecosystem Component for the Northwest Fork.
- Results of vegetation surveys indicated that a unharmed, healthy floodplain swamp community exists and river mile 10.2, a “stressed” community exists at river mile 9.7, and those communities that remain at river mile 9.2 has been significantly harmed (**Tables 30-32, Figure 26**).
- Comparison of vegetation along the river based on aerial photography, indicates that floodplain vegetation in the upstream areas of the river changed significantly between 1940 and 1995 (Figures 27-30, Table 33), but has shown very little change between 1985 and 1995 (**Table 33, Figures 29** and **31**). These data suggest that the improved hydrologic conditions may have stabilized or slowed the trend of river floodplain degradation.

- Since long-term salinity records did not exist for the each vegetation site sampled along the Northwest Fork of the river, a hydrodynamic/salinity model was used to simulate a long-term (30 years) time series of salinity conditions at each site. For each time series, descriptive statistics (mean, standard deviation, 90th percentile, maximum) were developed to characterize salinity regimes at each vegetation sampling site (**Table 34).**
- The data were also expressed in terms of the amount and percent of time that salinities of different levels occurred at each station (**Table 35**) and the return frequency and duration that each site was exposed to salinity levels during the 30 year simulation (**Table 36**).
- Results showed that at river mile 10.2 (within the unharmed, healthy floodplain swamp community) salinities ranged from 0 up to 3 parts per thousand (ppt) with a mean salinity of 0.15 ppt and a 90th percentile of 0.65 ppt during the 30 year simulation. These data indicate that this portion of the river is a freshwater system except during low flow periods when mean daily salinities may exceed 2 ppt for 20 days every six years. At this site, average salinities were 2 ppt or above for only 1% of the simulation period. Salinity exceeded 3 ppt only once, for a 13-day period, during the 30-year simulation period.
- Downstream at river mile 9.7 (the stressed floodplain swamp community) daily mean salinity levels ranged from 0 up to 6 ppt with a mean salinity of 0.5 ppt and 90th percentile limit of 1.7 ppt during the 30 year simulation. This represents about a three-fold increase in mean salinity as compared to the healthy floodplain swamp community located at river mile 10.2. Salinities at river mile 9.7 exceeded 2 ppt for an average of 40 days, once every 1.25 years. Average salinities were 2 ppt or greater during 8 percent of the simulation period. Salinities were 3 ppt or more during 4 percent of the simulation period.
- Further downstream at river mile 9.2 (the significantly harmed site) salinity levels ranged from 0 to 9 ppt with a mean salinity of 0.97 ppt and 90th percentile limit of 2.9 ppt recorded over the 30 year simulation. Overall, this represents about a six-fold increase in mean salinity as compared to the site at river mile 10.2. At this site, salinity levels exceeded 2 ppt twice ayear for an average of 46 days, at return intervals of about seven months. Average salinities of 2 ppt or greater occurred about 18 percent of the simulation period. Salinities of 3 ppt or more occurred during 12 percent of the simulation period.
- A flow/salinity relationship was established for each of the seven vegetation sampling sites, based on output of a hydrodynamic/salinity model (**Table 37**). These data show the amount of flow (as measured at the Lainhart Dam) required to maintain average salinity conditions at different points located along the river. These data may also be used to estimate the flows required to maintain desired salinity conditions at different locations on the Northwest Fork.

Application of the River Vegetation/Salinity (SAVELOX) Model

Using the vegetation survey results and the salinity time series generated from the hydrodynamic model, correlation analyses were used to examine vegetation trends relative to salinity event duration. From these data, a river vegetation/salinity model (SAVELOX) was developed using an empirical approach to extrapolate vegetation parameter response given a set of long-term salinity conditions (see **Chapter 4**). The model formulas were based upon the correlation between measured vegetation parameters (i.e. abundance, height of adults, canopy cover, etc.) and a calculated salinity ratio *Ds/Db* at those sites where both computed salinity and vegetation survey data existed.

SAVELOX Model Results

Relationships between vegetation trends and long-term salinity conditions along the Northwest Fork were determined (**Table 38**) and expressed as relational formulas that were the basis for the SAVELOX model. A predicted value for a given vegetation parameter was calculated from the following user input: 1) selection of a mean salinity event threshold (≥1 ppt, ≥2 ppt, or ≥3 ppt); and 2) long-term mean salinity event duration and mean time between salinity event for a location along the Northwest Fork. The model output is a predicted value for a vegetation parameter at a location along the Northwest Fork. Model output was verified using additional intermediate site vegetation data collected along the Northwest Fork (V-1, V-2, V-3, etc., **Figure 16, Chapter 4**) which were not used in development of the formulas.

Table 38. Estimated Salinity Event Ratio (*Ds/Db*) at a 2 ppt Threshold Associated with a Decline of Measured Freshwater Vegetation Parameters

Species	Abundance Index		No. of Adults Per Site[4]		Canopy Coverage (Adults)		Mean Height (Adults)		Mean DBH (Adults)		No. of Juveniles Per Site[4]	
	Dec[1]	NP[2]	Dec	NP	Dec	<5%	Dec	NP	Dec	NP	Dec	NP
Bald Cypress	0.28	5.00[5]	0.13	5.00[5]	0.13	0.38	N/A	5.00[5]	N/A	5.00[5]	0.13	0.52
V. Willow	0.13	0.13	0.13	0.28	N/A	N/A	N/A	0.28	N/A	N/A	0.13	0.28
Dahoon	0.13	0.52	0.13	0.33	N/A	N/A	0.13	0.33	0.13	0.33	0.13	0.28
Pop Ash	0.28	0.52	0.28	0.52	0.13	0.28	0.28	0.52	0.13	0.52	0.28	0.28
Pond Apple	1.26	1.26	0.28	1.22	0.13	0.60	0.28	1.22	0.28	0.60	0.28	0.28
Red Maple	0.13	0.75	0.28	0.28	0.13	0.28	0.28	0.28	0.13	0.28	0.13	0.13

[1] Dec = Most downstream point of the river where the vegetation parameter (Ds/Db) was observed to decline below background levels; where a drop in the value was first noted (moving from upstream to downstream)
[2] NP = Most downstream point of the river where the vegetation parameter was either no longer present, where the value first reached zero, or where there were no individuals found (moving from upstream to downstream)
[3] N/A = not able to be determined from the data
[4] Based upon combined totals from both plots surveyed at a site
[5] Indicates an estimated value

Table 38 shows the salinity ratio threshold associated with a decline in or a value of zero for each measured vegetation parameter for several key species. Using the SAVELOX model, this information can be expanded to include salinity event magnitude (threshold ≥1 ppt, ≥2 ppt, or ≥3 ppt), duration, frequency, location (expressed as river mile) and the corresponding estimated minimum flow over Lainhart Dam required to keep salinity below the threshold value. An example of SAVELOX model results are shown for red maple in **Table 39**.

Based on these model results and outputs, it is possible to predict the future distribution of the six VEC species along the Northwest Fork, based on the following:

- The model provides the capability to analyze future water management scenarios that predict hydrologic conditions and flow patterns in the river to determine the resulting salinity regime.

Table 39. Output of the SAVELOX Model: Mean Salinity Event $\geq$2 ppt Duration (days), Mean Time Between Events (days), and Flow (cfs*) associated with community vegetation parameter changes in Red Maple (*Acer rubrum*)

Red Maple					
Vegetation Parameter	**Change in Parameter**	**River Mile**	**Event >2 ppt Duration (days)**	**Event >2 ppt Frequency (days)**	**Lainhart Flow (cfs)***
Abundance Index	Decline[1]	9.7	42	320	30
	Not Present[2]	8.7	60	76	65
Number of Adults Per Site	Decline	9.2	44	157	40
	Not Present	9.2	44	157	40
Canopy Coverage (Adults)	Decline	9.7	42	320	30
	Not Present	9.2	44	157	40
Mean Tree Height (Adults)	Decline	9.2	44	157	40
	Not Present	9.2	44	157	40
Mean DBH (Adults)	Decline	9.7	42	320	30
	Not Present	9.2	44	157	40
Number of Juveniles Per Site	Decline	9.7	42	320	30
	Not Present	9.7	42	320	30

CFS = cubic feet per second

[1] Decline = Most downstream point of the river where the vegetation parameter was observed to decline below background levels; where a drop in the value was first noted (moving from upstream to downstream)

[2] Not Present = Most downstream point of the river where the vegetation parameter was either no longer present, where the value first reached zero, or where there were no individuals found (moving from upstream to downstream)

- Based on empirical data derived from healthy stressed and damaged plant communities that presently exist on the river, the model can be used to predict the downstream distribution limits (in river miles) of the healthy freshwater floodplain swamp community or any of its component species.
- In addition it can be used to determine areas where the freshwater swamp community or its component species will be stressed, and locations where significant harm occurs to this community.
- The model can also be used to predict what flow conditions are necessary to protect or restore these species and the floodplain community.

DEVELOPMENT OF RESOURCE PROTECTION CRITERIA.

Results of the quantitative data from the river vegetation survey have shown that a relatively non-impacted, “healthy”, sustainable floodplain swamp community exists at river mile 10.2. Results of the semi-quantitative sampling indicates that these plant communities remain healthy as far downstream as river mile 9.9.

It should be noted that although there is a direct correlation between presence, abundance and health of “freshwater” forest species and distance from the inlet and that there is a corresponding inverse correlation with salinity concentrations in the river, these correlations do not prove a cause-effect relationship. Specific data on salt tolerances of these six species would be required to establish that salt water exposure was responsible for changes in vegetation along the river channel. We have not been able to obtain such evidence and have had to rely on general information that is provide in the literature such as that shown in **Table 29.** Nevertheless, it appears, based at least on empirical evidence from this particular river system, that salinity can at least be considered as a surrogate for stress factors that presently limit the downstream distribution of the floodplain swamp community along the Northwest Fork.

The salinity conditions that occur at river mile 10.2 are essentially those of a freshwater system, except during dry periods when mean daily salinities may increase up to 2 ppt (**Figure 30**). Model simulations show that such elevated salinity conditions have occurred, on average, for periods of about 20 days, once every six years (**Table 36).** Review of these data indicate that salinity conditions that exist at river mile 10.2 provide a viable and sustainable freshwater floodplain swamp community. More strenuous conditions in terms of magnitude, frequency or duration of salinity exposure, such as those experienced downstream at station 9.7, lead to stress of the freshwater swamp community. Exposure to more severe salinity conditions, such as those that occur at station 9.2, have resulted in significant harm to the floodplain swamp community.

Although there may be a basis to define a “minimum” flow for the river based on a “maximum allowable salinity event,” the ability of plant communities to survive such periodic impacts depends on the health of the community prior to exposure. Since the resource to be protected is a freshwater plant community, the ideal conditions would be to not allow any salt water to enter this system. If the community is healthy, by virtue of not having been exposed to salt water for a long period, it can tolerate occasional salinity stress. Likewise if the stress period is followed by a long period when no salt is present, the community can effectively recover.

By contrast, if salinity stress occurs frequently, the community will become increasingly damaged, will not have time to recover and will continue to degrade. This progressive damage may occur due to the direct effects of salt toxicity and/or secondary effects such as a) reduced resistance to insects and diseases, b) competition by more salt-tolerant species such as mangroves, and c) reduced growth and reproductive success. In summary, a robust freshwater floodplain swamp community that has a history of non-exposure to salinity intrusion is better able to survive an occasional increase in salt content than a community that has been stressed by frequent exposure to elevated (although perhaps non-lethal) salinity conditions.

Repeated low-level salinity stress may be sufficient to prevent seed germination and/or to kill newly-sprouted seedlings and saplings of freshwater species without killing the adult plants. In this case, the plant “community” may continue to exist for some time, but without recruitment of new individuals. In this case, the community is not sustainable and will eventually die out and be replaced by saltwater-tolerant species.

The MFL is based on the amount of flow that is required to protect a primarily freshwater system from significant harm when exposed to short-duration, infrequent events that have limited allowable salinity concentrations. Several different salinity criteria were examined as a basis to ensure that the resource was adequately protected. The purpose of this effort was to determine parameters that could be effectively measured in the field, derived from field data or from model simulations and that could be empirically linked to resource impacts.

Based on the analyses and considerations described above, SFWMD staff conclude that to continue to protect the habitat values, species composition, and canopy structure of the existing healthy floodplain swamp community that exists at station 10B (river mile 10.2) and extends downstream to river mile 9.9, average salinity conditions, as determined by the model, should be maintained at or below 0.15 ppt. Daily mean salinity should not be allowed to exceed 1 ppt more than 5 percent of the time (40 days per year), 2 ppt more than 1 percent of the time (30 days in four years) and should not exceed 3 ppt more than 20 days in 10 years (see **Tables 34 and 35).** This indicates that to provide adequate protection for the resource, a range of flow, duration and frequency criteria can be defined for this station as represented in the first line of **Table 40.** A number of previous authors have identified the 2 ppt threshold as being an effective indicator of saltwater contamination because this concentration is significantly higher than background concentrations of salts that might be derived from other sources such as runoff or mineralized groundwater flow. Previous studies have shown generally good correlation between measured values and the locations of the 2 ppt isohaline contours that were predicted by the hydrodynamic model for this river system.

Although a daily mean concentration of 2 ppt is easily estimated from the hydrodynamic/salinity model, it is not clear how this predicted mean salinity relates to the actual range of salinity conditions that may be experienced at a particular location during a 24-hour period. The SFWMD is in the process of upgrading the Loxahatchee River hydrodynamic model to three dimensions and establishing a more effective monitoring program in the river to address this issue.

Table 40 Various Salinity parameters that can be used to protect the resource

River Mile	Flows (cfs)needed to maintain mean salinity concentrations:				
	Mean ≤ 0.15 ppt	Mean ≤ 0.3 ppt	≤ 1ppt (96%) 40 days/yr	≤ 2ppt (99%) 30 days/4yr	Salinity ≤ 3 ppt 20days/10yr
10.2	50	**35**	20	10	5
9.7	85	50	**32**	25	15
9.2	100	65	47	**35**	**22**
8.9	150	85	60	42	**27**
8.6	150	120	75	55	42
8.35	200	130	80	65	52

Previous studies have also shown that salinity concentrations in the river are stratified (i.e. low salinity or fresh water is present at the top of the water column and higher salinity water is located at the bottom). Since the two-dimensional model represents a "vertically averaged" salinity, a predicted daily average value of 2 ppt at a particular point in the river is assumed to represent salinity values that range from perhaps 4 ppt at the bottom of the river channel to near fresh water conditions at the surface. Also, since the salinity represents a daily average, there may be a considerable variation at a given point between high tide and low tide conditions, so that a daily average bottom salinity of 4 ppt could potentially represent a low tide bottom salinity of 0 ppt and a high tide bottom salinity of 8 ppt. Salinities of above 7 ppt have been measured in the river upstream of mile marker 10 during an extreme drought condition (Russell and McPherson 1984). Modeling results presented in this study indicate that average salinities as high as 3.5 ppt may occur at this location during an extreme low flow condition.

Data from this study suggest that the 2 ppt isohaline (representing a maximum of perhaps 4 ppt salinity at the bottom of the water column) may have particular relevance to the protection of the freshwater floodplain swamp community. This level is exceeded only about once every 6 years in healthy communities such as those at river mile 10.2. This low rate of occurrence is reflective of historical regional rainfall patterns and is apparently sufficient enough to allow the community to recover to a healthy condition between events. Salinity exposure is sufficiently infrequent to allow seeds to germinate successfully and grow beyond the most sensitive life stages.

In contrast, a daily mean salinity of 2 ppt is exceeded about once every year in the "stressed" communities (river mile 9.7), and is exceeded about once every 160 days in communities that have experienced significant harm (river mile 9.2) (**Table 35).** These relatively low levels of exposure are apparently sufficient enough to result in loss of canopy cover and reduced growth and prevent successful seed germination and subsequent survival of VEC species. Data collected in this study, and information compiled from literature reviews of the salinity tolerance of freshwater vegetation also suggest that seedlings and saplings characteristic of freshwater floodplain swamp communities may be more acutely sensitive to salt concentrations between 3 and 6 ppt. This sensitivity is indicated by a loss of saplings and seedlings of VEC species at river mile 9.7. Exposure to mean daily salinities above 3 ppt occurs approximately once every 2.5 years (34 days out 29 months) at river mile 9.7.

Definitions of No Harm, Stressed and Significant Harm

Based on results of the above field studies, modeling, and data analyses, the following criteria were developed to define a non-impacted, healthy, sustainable floodplain swamp community (the "No Harm" condition) for the Northwest Fork of the Loxahatchee River as well as various other degrees of impacts -- "stressed" and "significant harm" -- as discussed below.

No Harm

The area of the river that characterizes the "no harm" condition is typified by those vegetation communities that were documented in quantitative studies to occur at river mile 10.2.

- All six VEC species are present within the floodplain swamp community.
- The floodplain swamp consists of a high canopy of bald cypress and mixed hardwoods, approximately 35 - 60 ft. in height; a subcanopy of mixed hardwoods, 15-30 ft. in height, and an understory of more than 30 species of vascular plant species.
- Seedlings, saplings and adults of the six VEC species are present, indicating that the community is reproducing and sustainable.
- Results showed that at river mile 10.2, located within the unharmed, healthy floodplain swamp community, mean daily salinity levels ranged from 0 up to 3 parts per thousand (ppt) with a mean daily salinity of 0.15 ppt and a 90th percentile limit of 0.65 ppt during the 30 year simulation. This portion of the river is essentially a freshwater system except during low flow periods when salinities may exceed 1 ppt for 30 days once every two years, and 2 ppt for about 20 days, once every six years.

Stressed

At river mile 9.7, the floodplain swamp has been identified as “stressed” in response to elevated salinity concentrations experienced during low flow conditions. This community is characterized as follows:

- Most of the six VEC species are present, however they are reduced in abundance, tree height, and trunk diameter.
- The total number of other plant species is reduced, most notably a reduction in herbaceous species.
- A measurable change in the floodplain forest canopy structure is observed
- Although seedlings and saplings are present, they are reduced in number.
- The long-term salinity record at river mile 9.7 shows that during drought periods this area of the river has been exposed to more frequent occurrences of saline conditions as compared to the “no harm” condition.
- Daily mean salinity levels predicted by the model ranged from 0 up to 6 ppt with a mean salinity of 0.5 ppt and 90th percentile limit of 1.7 ppt during the 30 year simulation. This represents about a three-fold increase in salinity as compared to river mile 10.2. At river mile 9.7 salinity levels exceeded 1 ppt for about 40 days, twice a year, and exceeded 2 ppt about 40 days about once a year.

Significant Harm

Significant harm is defined as *the temporary loss of water resource functions which result from a change in surface or ground water hydrology, that takes more than two years to recover, but which is considered less severe than serious harm* (Chapter 40E-8, F.A.C.). Based on the data presented in this report, significant harm has occurred when:

- Two or more of the six VEC species are no longer present within the floodplain swamp landscape. Based on the results of the river vegetation survey, three of these key species (red bay, Virginia willow, and red maple) are no longer present at river mile 9.2.
- The total number of species present is reduced by about one-third as compared to values recorded upstream of river mile 10.2.
- The floodplain swamp high canopy is no longer present and has been replaced by a low canopy dominated by saltwater tolerant mangroves.
- Seedlings of the six VEC species are no longer present indicating this area can no longer support a reproducing floodplain swamp community.
- At river mile 9.2, daily mean salinity levels ranged from 0 up to 9 parts per thousand (ppt) with a mean salinity of 0.97 ppt and a 90th percentile limit of 2.9 ppt during the 30 year simulation. Overall this represents about a six-fold increase in mean salinity as compared to river mile 10.2. At this site salinity levels exceeded 1 ppt for about 55 days, twice a year and exceeded 2 ppt for 45 days for about once a year.

- Based on these data, river mile 9.2 represents the point in the river where significant harm occurs. Upstream of this point both healthy and salinity "stressed" floodplain vegetation communities continue to exist. Downstream of river mile 9.2 the freshwater dominated floodplain swamp and its associated high canopy are no longer present and have been replaced by saltwater tolerant red mangrove communities with a few remaining stands of bald cypress and cabbage palm trees.

Proposed Minimum Flow Criteria

Basis of Proposed Criteria

Protection from Harm

Based on the results of this study, the flow/salinity regime recorded upstream at river mile 10.2 currently supports an unharmed, healthy, sustainable floodplain swamp community. It is the District's intention to reproduce this salinity regime downstream at river mile 9.2, the point in the river where significant harm has been shown to occur. Using relationships developed from output of a hydrodynamic/salinity model (**Table 40),** a flow regime is needed that will provide essentially freshwater conditions (long-term average salinities of 0.1 to 0.2 ppt) at river mile 9.2. These conditions can be met by providing flows comparable to those provided historically, during average wet and dry season conditions as shown in **Table 24**. It is the intent of the District to provide such flows whenever possible.

Protection from Significant Harm

However during very dry periods, Lainhart Dam flows may be substantially reduced as upstream sources are depleted. Under such dry conditions, sufficient flow should be provided to the river to prevent the salinity regime at river mile 9.2 from exceeding 2 ppt for any longer time than has occurred within the "healthy" floodplain swamp community. Such events should not last for more than 20 days duration, and not occur more often than once every six years, in order not to exceed the salinity regime recorded upstream at river mile 10.2. Review of the flow/salinity relationships shown in **Table 40** indicates that in order to maintain mean daily salinity below 2 ppt at river mile 9.2, the Lainhart Dam needs to provide a minimum flow of at least 35-cfs to the Northwest Fork of the river.

In summary, proposed minimum flow criteria for the Loxahatchee River and Estuary were based on the following:

- Research conducted by the SFWMD identified locations on the river where both a "healthy" and a "stressed" floodplain swamp exist (at river miles 10.2 and 9.7, respectively), and identification of downstream locations where significant harm to this community is presently occurring (river mile 9.2).
- In order to protect the remaining healthy and stressed floodplain swamp community and the area that is presently experiencing significant harm, sufficient flow should be provided from

the Lainhart Dam whenever possible to prevent harm to the resource by maintaining essentially freshwater conditions in the Northwest Fork upstream of river mile 9.2.

- Modeling results indicate that flows at or below 35 cubic feet per second from Lainhart Dam, which occur frequently and for extended periods of time under present conditions, cause salinities in excess of 2 ppt to occur at sites where remaining stressed and damaged plant communities exist along the Northwest Fork. The VEC plant communities identified in this study should not be exposed to this level of salinity for more 20 days, more than once very six years in order to prevent significant harm.
- It is recognized that during periods of regional drought, the 35-cfs flow target may not be achievable. In order to prevent damage or stress from occurring to the floodplain swamp community at river mile 10.2 and significant harm from occurring at river mile 9.2, freshwater flows should not be allowed to decline below a discharge rate of 35 cfs at the Lainhart Dam for a period of more than 20 days, more often than once every six years.

Technical Criteria

The proposed technical criteria for minimum flows to the Northwest Fork of the Loxahatchee River are as follows:

Mean monthly flows of sufficient quantities of fresh water from the Lainhart Dam are required to maintain a healthy floodplain swamp and associated bald cypress habitat and prevent harm to this resource. This community has been identified as a valued ecosystem component of the Wild and Scenic portion of the Northwest Fork of the Loxahatchee River. During extreme dry periods, flows from Lainhart Dam may be reduced as upstream sources are depleted. If flows fall below 35 cfs for more than 20 days, the minimum flow and level criteria will be exceeded and harm will occur to floodplain resources. If these criteria are exceeded more frequently than once every six years, then significant harm and a violation of the minimum flow criteria will occur.